Alliance OF AUTOMOBILE MANUFACTURERS

July 27, 2004

Mr. Stephen R. Kratzke
Associate Administrator for Rulemaking
National Highway Traffic
Safety Administration
U.S. Department of Transportation
400 Seventh Street, S.W.
Washington, DC 20590

**Re: Federal Motor Vehicle Safety Standards; Occupant Crash Protection (Offset Frontal Crash); Request for Comments (69 Fed. Reg. 5108, February 3, 2004) Docket No. NHTSA 2003-15715, Notice 1**

Dear Mr. Kratzke:

The Alliance of Automobile Manufacturers (Alliance), a trade association of nine automobile manufacturers, including BMW Group, DaimlerChrysler, Ford Motor Company, General Motors, Mazda, Mitsubishi Motors, Porsche, Toyota, and Volkswagen, responds to NHTSA's Request for Comments (RFC) referenced above. This notice seeks comments on whether the agency should propose a high speed offset frontal crash test requirement to more fully address the potential for lower extremity injury in frontal crashes, specifically knee ligament, tibia, and ankle injuries.

The Alliance supports NHTSA's efforts to provide this opportunity for public comment on the appropriateness of proposing regulatory requirements governing offset frontal crash test performance criteria to measure protection for lower extremities. The Insurance Institute for Highway Safety (IIHS) offset deformable barrier (ODB) test program has reduced passenger compartment intrusion in new vehicles and will continue to do so in the future. However, additional field data research is still required to identify and understand lower extremity injury mechanisms, including the sources of deceleration-related injuries as compared to intrusion-related injuries. Further, decisions concerning the choice of an appropriate anthropomorphic test device and injury criteria are also needed.

The Alliance shares the agency's concern that some design changes that may improve certain vehicles' performance in high speed frontal offset crash tests "may result in adverse effects on the occupants of their collision partners."[1] These concerns must be addressed before NHTSA proceeds to a rulemaking proposal. The Alliance suggests that any disbenefits resulting from the adoption of a high speed offset crash requirement may

[1] 69 FR 5108

be reduced if the offset test configuration is harmonized with the current ECE R94 test which is conducted at 56 km/h. The Alliance recommends that the agency evaluate whether the test parameters prescribed in ECE R94 provide an acceptable balance between self-protection and partner-protection for belted and unbelted occupants. This evaluation should, in particular, consider the mass ceilings on vehicles that would be required to meet the ECE standard.

The Alliance suggests that it is premature for NHTSA to propose a high speed offset frontal crash test as a Federal Motor Vehicle Safety Standard at this time. Although NHTSA has been working on this issue since at least Fiscal Year 1997, when Congress directed the agency to work toward "establishing a federal motor vehicle safety standard for frontal offset crash testing,"[2] and provided NHTSA with funding for vehicle crash testing, too many questions remain unanswered about possible safety trade-offs to ensure that a frontal offset crash test safety standard would "meet the need for motor vehicle safety."[3] The questions pertain to self-/partner-protection, belted-/unbelted-occupants, and intrusion-/acceleration-related lower extremity injury.

To aid the agency in addressing these issues, the Alliance has included as a separate attachment, a proposed research plan. This research plan would facilitate the development of a vehicle crash test providing the most effective approach for reducing the frequency and severity of lower extremity injuries occurring in the field. Another attachment provides the Alliance's views on the first three of the ten questions posed by NHTSA at the conclusion of its RFC. Alliance members, in their individual responses, may address responses to the other seven questions posed by the agency.

In conclusion, the Alliance believes that numerous issues and analyses associated with the agency proposing a high speed offset frontal crash test requirement remain outstanding. For this reason, and because the potential benefits and disbenefits of such a rulemaking have not been fully and rigorously quantified, the Alliance suggests further research and analysis is needed to support a decision by NHTSA on whether to proceed with a rulemaking proposal.

Sincerely,

Robert Strassburger
Vice President
Vehicle Safety and Harmonization
Alliance of Automobile Manufacturers

Attachments

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[2] 69 FR 5108

[3] 49 USC 30111

**ATTACHMENT 1**
**Alliance Response to NHTSA Questions 1, 2, and 3**

Question 1: Are NHTSA's anticipated safety benefits associated from a fixed offset deformable barrier crash test requirement provided in Section IV realistic? Please provide data to support any views.

Response: NHTSA's safety benefits estimates neither provide the agency's methodology for estimating the number of people injured annually in frontal offset crashes, nor evaluate the effectiveness of an offset frontal crash test requirement in reducing these injury counts.

Additionally, NHTSA's benefits analysis does not consider potentially significant trade-offs (benefits/disbenefits) for different vehicle types in different real-world crash modes that can be expected if both passenger cars and light trucks are required to meet a higher speed offset crash test. Later in this response, the Alliance provides a suggested research plan to address these issues.

Question 2: In addition to potential disbenefits to the occupants of collision partners described in this notice, are there other potential disbenefits NHTSA should consider? Please provide data to support any views.

Response: Yes, there are potential disbenefits beyond those the agency described in this notice. The agency must proceed cautiously so as to understand, via continued research, the influence that new regulatory requirements may have in generating unintended disbenefits to the US motoring public. Certain vehicles designed to meet a higher speed belted offset barrier test may require crash design attributes and performance characteristics that would be in conflict with design attributes and performance characteristics necessary for optimal vehicle-to-vehicle crash performance. The precise detail of the conflicts will depend upon the mass, geometry, and stiffness attributes of both colliding vehicles. Optimizing crash performance of a vehicle to meet a higher speed offset crash test may sub-optimize the crash performance for that same vehicle and its impacted partner during a vehicle-to-vehicle collision, depending upon the mass, geometry, and stiffness attributes of the colliding vehicles. For example, there is typically very little intrusion in vehicle-to-vehicle collisions below 25 mph. In a paper presented at the 39th Annual meeting of the Association for the Advancement of Automotive Medicine October 1995, Crandall, et al University of Virginia and Dischinger, et. al., University of Maryland at Baltimore conclude:

*Over 93% of the vehicles involved in frontal crashes exhibit less than 3 cm of footwell intrusion and the majority of these crashes occur at a delta-V in the 10km/h to 30km/h range. Although less than 2% of the occupants in these crashes sustain below-knee injuries, they comprise the majority of those who are injured due to the frequency of these crash conditions. P 273 (Table 3)*

Depending on the specific design of the vehicle, a vehicle stiffened to meet the requirements of a high speed offset test may suffer an increase in the severity of low-speed crashes to occupants, resulting in a potential increase in all low-speed injuries including AIS 2+ lower extremity injuries. These increases will be greater for unbelted than for belted occupants. In other words, a high-speed offset deformable barrier test could potentially lead to vehicles so stiff that acceleration-based injuries may occur more frequently than they do today. If NHTSA formally proposes an offset frontal crash test requirement, the agency should consider the test speed and the subject vehicles carefully so as not to require structural modifications that might result in increases of stiffness to vehicle front structures. The potential disbenefits may be reduced if the offset test configuration is harmonized with the current 56 km/h ECE R94 test. The agency should carefully consider if the test parameters prescribed in ECE R94 provide an acceptable balance between self-protection and partner-protection for belted and unbelted occupants.

There are other possible disbenefits to such a test requirement that may require additional vehicle changes to try to counteract these effects:

1. The test requirement could lead to vehicle mass increases. Vehicle mass increases may reduce fuel economy, as well as braking effectiveness.
2. Increased rollover risk resulting from mass increases which, depending on where offset-frontal countermeasures are placed in a particular vehicle, could raise the location of the vehicle's center of gravity.
3. Increased frontal stiffness may increase side impact injuries to collision partner vehicles.
4. Increased stiffness may degrade restrained and unrestrained occupant performance in full frontal crashes.
5. Increased stiffness may degrade rear seat occupant, particularly child, safety performance, to the extent that injuries are acceleration based, as opposed to intrusion based.
6. A focus on reducing intrusion in a frontal offset crash test may lead to design changes that increase the potential for other, e.g. hip, injuries. More detailed analyses of crash reports may provide a better understanding of the mechanisms of lower extremity injuries.

Question 3: Is it necessary to stiffen the frontal corners of vehicles to do well in a fixed offset deformable barrier crash test? Please explain the answer. Also, is the answer to this question different for different classes? If so, please explain the answer for each vehicle class.

Response: It is not clear what NHTSA means by "stiffening the front corners." Certainly, for some vehicles to meet such a test requirement, vehicle crash structures and load path configuration modifications would be necessary to accommodate the higher speed offset barrier crash mode. Depending on the specific design and mass of the vehicle, this may result in an increase in the overall stiffness of these vehicles' frontal crash structures. Limiting this question only to an examination of front corner stiffness will not account for countermeasures used in other areas of the vehicle. Where to "stiffen" a vehicle is always dependent upon a specific vehicle's performance in crash tests and crash test simulations, observing where vehicle deformation occurs and how deformation relates to injury causation.

Efforts aimed at improving vehicle performance in NCAP full-frontal and Insurance Institute for Highway Safety (IIHS) offset-frontal tests may have, in general, led to increased vehicle stiffness. The stiffness level generated by a vehicle's front structures is a significant factor in managing vehicle crash compatibility. With the United States vehicle fleet mix becoming more diverse with greater numbers of light trucks, multi-purpose vehicles and sport utility vehicles, consideration of effective means of managing the effects on "collision partner" vehicles, i.e., "crash compatibility" has become imperative. NHTSA's NCAP and IIHS' offset-frontal testing have focused on providing enhanced "self-protection, but have not considered the possible unintended effects on collision compatibility between vehicles of differing sizes. The options for improving both occupant protection and crash-partner vehicle occupant protection may be limited by an offset frontal crash test requirement, especially for heavier mass vehicles.

**ATTACHMENT 2**
**Proposed Research Plan**

## A. Problem Identification/Verification

*Discussion:* The Alliance supports the NHTSA efforts to address the important issue of protection for the lower extremities. The IIHS ODB tests have reduced passenger compartment intrusion and will continue to do so in the future. However, additional field data research is still required to better identify and understand the mechanisms of lower extremity injuries. This research should include field crash data analyses outlining numbers of crashes involving lower extremity injuries, vehicle masses, impact speeds, crash configuration (full frontal, offset, degrees of offset, etc.), injury severity and mechanisms. Injury results for both striking and struck vehicle occupants need to be assessed, so that compatibility considerations can be addressed.

The agency's research demonstrates that the lower extremity assessment numbers often exceed the IARVs in both full-frontal rigid barrier testing (NCAP) and ODB testing. The agency's accident data analysis should attempt to identify the proportion of lower extremity injuries that could be addressed by an ODB test and the proportion of lower extremity injuries that could be addressed by a full-frontal rigid barrier test.

*Recommendation:* The Alliance recommends that a thorough comparison of field data to laboratory test data on lower extremity injury mechanisms be conducted before implementing a regulation governing acceptable levels of lower extremity injury in a vehicle crash test. The goal of this research is to determine if existing evaluations are already replicating a majority of the injury seen in the field. For example, in manufacturers' barrier and sled testing with the Denton leg, various injury mechanisms have been identified even in the absence of significant intrusion. These injury mechanisms include:

- Dorsiflexion limit - lower My – toe into front of dash
- Plantar Flexion limit – lower My – belted rearward occupant leg swing under I/P
- Inversion, eversion – lower Mx – roll off wheel well or accelerator
- Anterior tibia loading – lower & upper My – lower glove box hinge or I/P tiebars
- Acceleration based forces as foot contacts toeboard – lower shear plus tibia compression leading to upper My (upper index) - setup, pulse, floor geometry
- Clevis load imbalance – bolster system load inconsistencies

These mechanisms can be attributed to floor geometry, occupant leg kinematics, bolster construction, ATD setup procedure, and vehicle pulse. They vary from vehicle to vehicle, belted to unbelted occupants, and small to large ATD. However, it has not been verified that the mechanisms appearing in these tests represent the frequency, severity and type of injury mechanisms in the field. This knowledge is needed to demonstrate that reducing some or all of these mechanisms in an offset-frontal crash test environment reduces field incidents of lower extremity injury.

The Research Proposal for Problem Identification/Verification:

1. Consolidate current field knowledge on lower extremity injury. There is a wealth of information in existence but it is stored in various locations and with various levels of detail.
    a. Develop a database structure that specifies the information required to determine the appropriate laboratory test configuration. Data similar to that acquired by University of Michigan Transportation Research Institute (UMTRI) study, "Lower-Extremity Fractures/Dislocations in Offset-frontal Crashes" 9/19/99 *(appended as Attachment 3 to this submission)*, and in SAE Paper No. 922515[i] would be reasonable starting point. For example, the data acquired should include:
        i. Types and frequency of injury: inversion/eversion, dorsiflex/plantarflex, etc.
        ii. Vehicle conditions: floor geometry, contacts, bolster construction
        iii. Occupant data: M/F, large/small, belted/unbelted, seating location
        iv. Accident Information: severity, vehicle rotation, intrusion,
    b. Identify gaps in data and knowledge to completely specify a lower extremity evaluation(s).
    c. Extract appropriate NASS cases to conduct in-depth studies to provide the additional information.
    d. Examine CIREN databases to determine if they provide sufficient information.
    e. Organize an SCI-type study to guide determine the information in (a) above for current-design vehicles.

A more detailed field data, crash investigation methodology, developed by UMTRI, is provided as Attachment 4 to this document.

2. Consolidate full vehicle crash and sled test knowledge on lower extremity IARVs. Results would provide types of mechanisms and frequency categorized by occupant size, seating location, belted or unbelted, event severity, similar to how the field data is categorized. In addition, Thor-Lx data and Denton data would be evaluated separately.
    a. Using 20-25 mph unbelted 0-degree, normal seating, no intrusion
    b. Using 30-35 mph belted 0-degree, normal seating, by degree of intrusion
    c. Using 35-40 mph belted ODB, normal seating, struck side, by degree of intrusion
    d. Angle evaluations, pole evaluations

3. Compare field data to consolidated test knowledge. If mechanisms do not match in type and frequency, determine why.
    a. Evaluation setup differences
        i. Knees splayed
        ii. Feet on pedals
        iii. Occupants seated more rearward
        iv. Feet rearward, not flat

v. Other

b. Evaluate crash mode
c. Evaluate crash severity

4. Conduct vehicle or subsystem tests to confirm which tests best produce the injury mechanisms observed in the field. Conduct vehicle or subsystem tests with alternate ATD legs to determine if measurement device and not setup accounts for variation between field results and laboratory testing.
5. Recommend evaluation event, setup, and ATD(s) for condition(s) where lower extremity injury mechanisms best replicate field incidents.

**B. Vehicle Countermeasures**

*Discussion:* To improve and assess frontal offset test performance on both self-protection and crash partner occupant protection, an understanding of the effects of vehicle design changes is required. The agency's research on front-to-front compatibility is still in progress. Concurrently, research is being conducted in the private sector by the "Enhancing Vehicle-To-Vehicle Crash Compatibility" activity, as announced by the Alliance and the Insurance Institute for Highway Safety in December 2003.

*Recommendation:* Research by both bodies must attain a level of maturity before regulatory requirements can be devised and proposed by NHTSA. In the interim, the research on crash compatibility and should be closely coordinated along with other activities in this area.

**C. Test Procedures**

*Discussion:* From a technological standpoint, the agency's option of mass-dependent impact velocity based on definition of the self-protection requirements of the small reference car deserves consideration.

*Recommendation:* The agency should research this option in detail along with conducting an associated benefits analysis in order to assess the impact on self-protection as well as crash-partner protection.

Vehicle weight limitations in offset deformable barrier tests that are run at fixed speeds should be driven by the requirements of balancing self-protection and partner protection for heavier vehicles in collisions with lighter vehicles. Too high a test speed could lead to partner-protection issues in heavier vehicles such as SUVs and LTVs, and consequently an appropriate mass restriction is needed. The agency should undertake research to estimate the significance of a mass-adjusted test speed on the fleet in terms of self-protection and partner-protection.

**D. Test Device Assessment**

*Discussion:* There is an extensive level of experience in the industry in the usage of Denton lower extremity instrumentation in frontal crash tests. There is much less experience with the Thor-Lx instrumentation. In addition, the injury assessment limits for the Denton lower extremity instrumentation are based on earlier cadaver data. The injury assessment limits for Thor-Lx are based on more recent cadaver data. Moreover, the assessment values are not equivalent due to design differences between the two instrumented extremities.

*Recommendation:* The agency should conduct research aimed at shedding more light on the impact of these differences on crash test results, as well as developing equivalent injury criteria for the two instrumented extremities. The Alliance suggests that the agency test the Thor-Lx and the Denton-50M lower legs side by side with the same test set-up (component and barrier) as the means by which to most effectively, objectively and accurately evaluate the repeatability, reproducibility, durability, and ease of use of Thor-Lx in rigid barrier and ODB tests. . The same process should be followed for the $5^{th}$ percentile female versions of the leg segments.

Component Level Testing: The following component test method is suggested to provide Thor-Lx and Denton-50M data for dynamic response comparison:

- Linear impact testing of the Thor-Lx and Denton-50M lower legs. The test machine can adjust the type, speed, and weight of the impactor used.
- Impact location – upper, middle & lower tibia and various points on ball and heel of foot with and without a shoe (Dorsiflexion, Dorsi/Eversion, Dorsi/Inversion, Plantarflexion, Eversion, and Inversion).
- Travel – test setup should be capable of at least two inches travel after the impactor has made contact with the leg or foot
- Speed - approximately 9.5 mph for leg impact, approximately 9 mph for foot impact
- Weight – approximately 70 lbs for leg impact, approximately 55 lbs for foot impact
- Impactor shape - long cylindrical shaft that is perpendicular to the leg (shaft should be wider than the leg) for leg impacts and oval shape with the front edge flattened out for foot impacts.

Barrier Testing: The following full-scale barrier tests are suggested to provide Thor-Lx and Denton-50M data for dynamic response comparison:

- Test modes:
  - LHS 40% Offset with Thor-Lx legs and LHS 40% Offset with Denton-50M
  - Rigid full-frontal NCAP 56 km/h with Thor-Lx legs and rigid full-frontal NCAP 56 km/h with Denton-50M
  - Other test modes with both leg segments
- Speed – up to 56 km/h
- Both legs should be tested with the exact same vehicle and weight.
- An array of different vehicles should be tested (i.e., small car, passenger, & truck/SUV)
- ATD – 50% male driver and right-front passenger

Thor-Lx and Denton-50M Durability

- Component Level Testing: Inspect legs for structural damage and channel signals after every test.
- Barrier Testing: Conduct a structural and post-calibration test on both legs to see if every channel remained in the appropriate range during each vehicle crash for the Thor-Lx and Denton-50M lower legs.

Thor-Lx and Denton-50M Repeatability:

- Component Level Testing: A minimum of three tests for each impact point should be a minimum to test lower leg repeatability. A coefficient of variance should be calculated on each leg & foot impact point for both types of legs.

Thor-Lx and Denton-50M Reproducibility:

- Barrier Testing: Both legs should be tested no less than three times under the test conditions provided in the test plan. Both legs need to be subjected to a reproducibility study to ensure that test results fall within acceptable intervals.

Thor-Lx and Denton-50M Biofidelity:

- The research plan should look into the biofidelic difference between the Thor-Lx and the Denton-50M lower leg relating to performance differences.

**E. Benefits Analyses**

*Discussion:* The analysis submitted by the agency appears to be based on extremely limited data. In addition, the explanation presented by the agency as to how its benefits estimates were derived is inadequate to understand the rationale behind the agency's purported annual reduction estimate of 1,300 to 8,000 in MAIS 2+ lower extremity injuries. The agency acknowledged, in its docket submission, that "All estimates did not consider potential disbenefits from increased stiffness of vehicles." Finally, the agency did not estimate any potential benefits/disbenefits to other body regions, as noted earlier in our comments. These effects could be greater or less than the effects on legs and femurs.

The agency's analysis estimating annual safety benefits of 1,300 to 8,000 MAIS 2+ lower extremity injuries does not include the potential disbenefits associated with a possible increase in stiffness for some vehicles due to requiring an ODB test, particularly if the test speed were set greater than 56 km/h. A more detailed field accident data analysis including the potential disbenefits of high speed (> 56 km/h) ODB testing is required before the agency proceeds to formally propose an offset frontal test requirement.

The agency has submitted to the docket a brief analysis of its estimates of possible lower extremity injury benefits due to the ODB test, based on NASS/CDS data from 1995-

2001. Further, based on available test data, the agency estimated injury benefits to ODB tests at different impact speeds, as well with a moving deformable barrier (MDB) test, even though this latter test is not part of the agency's proposal. The agency included its benefit estimates for the Denton device as well as the Thor Lx. The agency's submission clearly demonstrates that the test data available was not uniform, and was often inconsistent. For example, the agency states in its analysis, "...the benefits results are counterintuitive" and "...the MDB benefit estimates... are also suspect." In the case of the MDB tests, no results for Thor-Lx were available. In the ODB tests at 64 km/h, 47 tests were available for the Denton device versus only 2 tests for the Thor Lx. In the 56 km/h ODB tests, no results for the Denton device were available. In general, except for the 64 km/h ODB tests conducted by IIHS using the $50^{th}$ % male Denton device, the data is limited to 7 tests or fewer per condition.

The agency indicated that it estimated the lower benefit bounds based on the measurements made with the $50^{th}$ % male Denton device in IIHS tests (64 km/h). The agency estimated the upper benefit bounds based on the unbelted $5^{th}$ % female, even though data was not available. The agency attempted to address this deficiency by assuming that the benefits to unbelted $5^{th}$ % females would be the same as the benefits to belted $50^{th}$ % males. The agency distinguished between the estimates for the Denton and the Thor Lx devices based on the consideration that the latter would include additional benefits to calcaneus and foot/ankle injuries.

*Recommendation:* To remedy the aforementioned deficiencies, the agency should collect substantially more test data to re-assess its benefits analysis, including the effects on other body regions. The agency should also clearly explain the manner in which the lower and the upper bounds on the benefits are estimated. The agency must also include a clear explanation of how the estimated benefits for THOR and Denton devices are calculated. Finally, the agency must take into account the potential disbenefits of the ODB test due to stiffening some vehicles' structures to realistically estimate the net safety benefits or disbenefits of an ODB test.

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[i] Lestina, D.C., Kuhlmann, T.P., Keats, T.E., and Alley, R. M, **"Mechanisms of Fracture in Ankle and Foot Injuries to Drivers in Motor Vehicle Crashes,"** SAE Paper No. 922515.

# Lower-Extremity Fractures/Dislocations in Offset-Frontal Crashes

## in the UMTRI Crash/Injury Database

as of 9/15/99

Larry Schneider
Joel MacWilliams

UMTRI

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Lower-Extremity Fractures/Dislocations in Offset-Frontal Crashes

## Offset-Frontal Crash Investigation Criteria

- Case vehicle is 1986 or later model (updated with project year)
- Offset-Frontal impact to case vehicle - i.e., %VOL < 100%
- Case vehicle is towed
- Driver and/or RF passenger restrained by belts, airbag, or both
- Injuries to restrained front-seat occupants
  - AIS > 2 any body region
  - AIS ≥ 1 for lower extremity
  - AIS ≥ 1 to any body region if attributed to intrusion
  - Any or no injuries if significant toepan intrusion

**Note: In last year or two, emphasis was on doing crashes with moderate to high impact severity and 25 < %Overlap < 75.**

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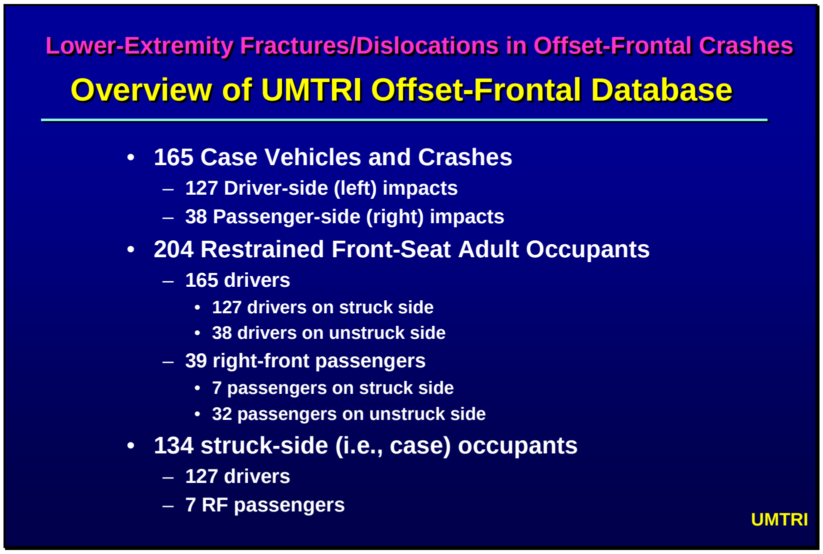

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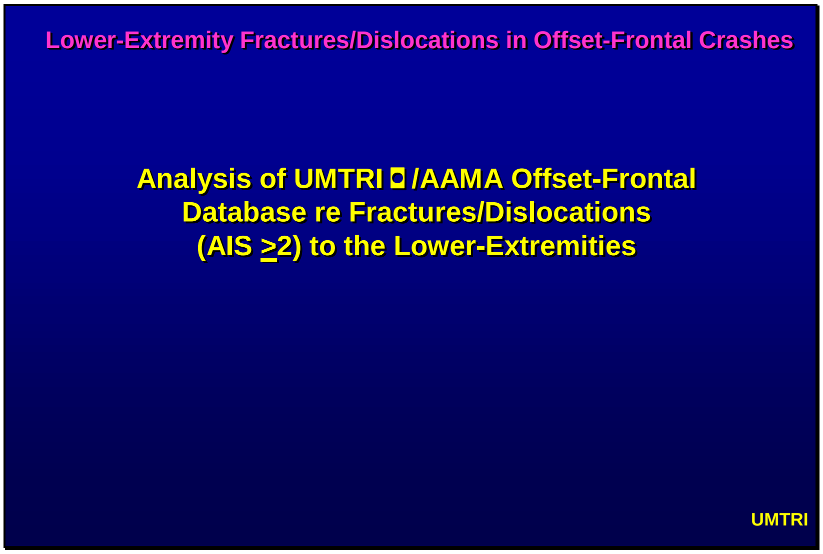
Lower-Extremity Fractures/Dislocations in Offset-Frontal Crashes
Analysis of UMTRI /AAMA Offset-Frontal Database re Fractures/Dislocations (AIS ≥2) to the Lower-Extremities
UMTRI

## Lower-Extremity Fractures/Dislocations in Offset-Frontal Crashes

### Database Analysis - Independent Variables

- Occupant Gender
- Occupant Age
- Occupant Weight
- Occupant Stature
- Occupant Location re Impacted Side (struck vs. unstruck)
- Restraint Usage
- Driver versus passenger?
- Vehicle Size Category - e.g., midsize, fullsize, large/luxury
- Vehicle Mass
- Impact Type
- Crash Severity (EBS/DeltaV)
- %Overlap (%VOL)
- PDOF
- Maximum Rearward Toepan Intrusion
- Maximum Rearward IP/Knee-Bolster Intrusion
- Braking and/or Bracing
- Angle of Impact - vehicle-to vehicle head-on crashes only
- Left versus right leg

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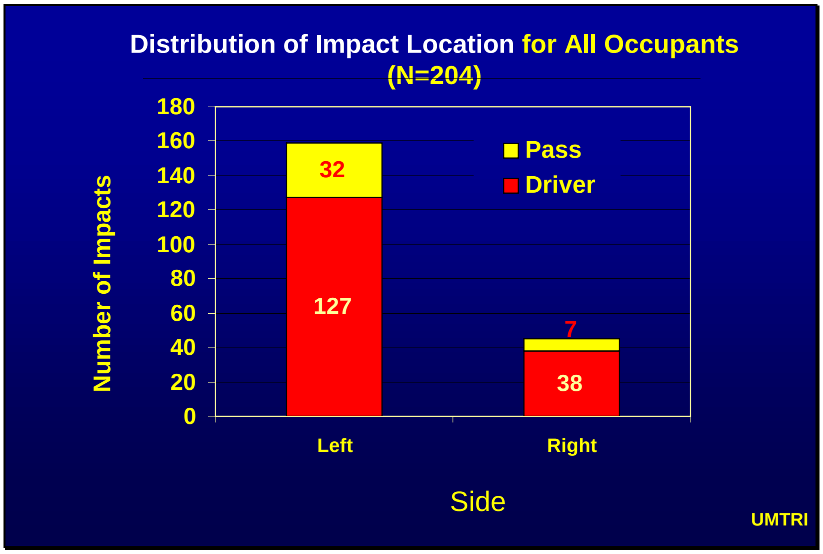

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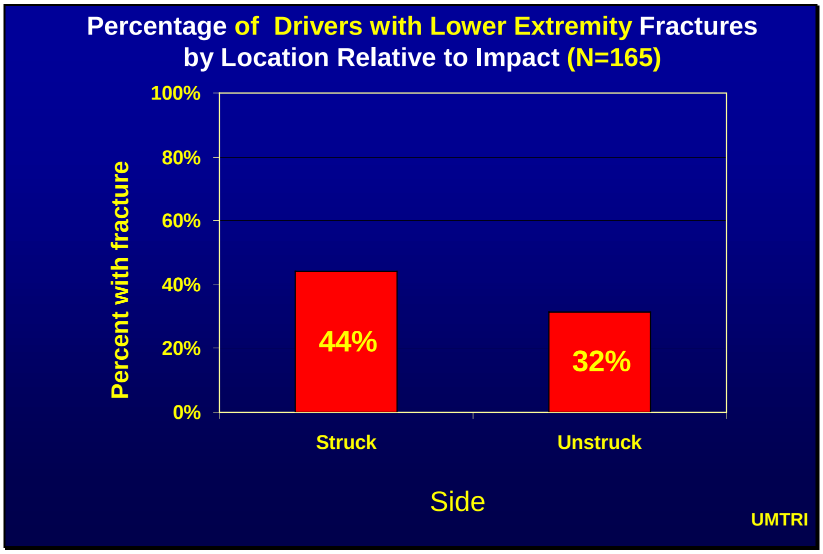

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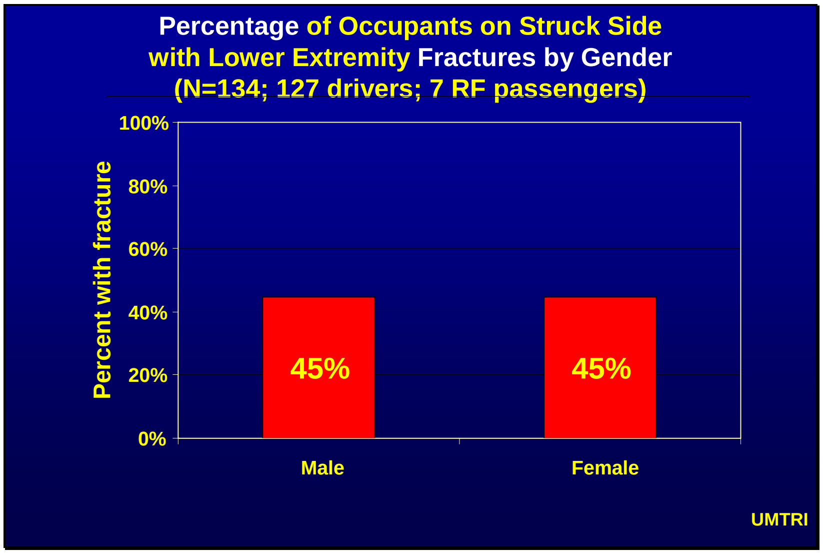
Percentage of Occupants on Struck Side
with Lower Extremity Fractures by Gender
(N=134; 127 drivers; 7 RF passengers)
Percent with fracture
100%
80%
60%
40%
20%
0%
45%
45%
Male
Female
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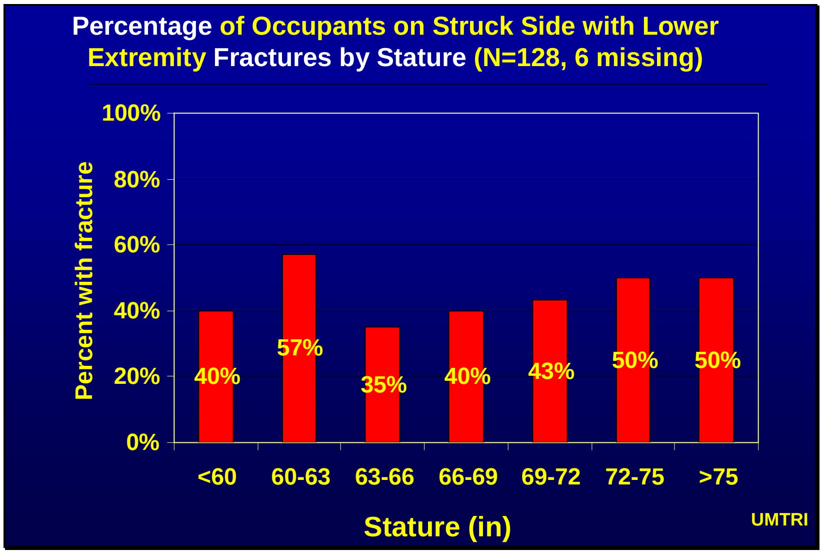

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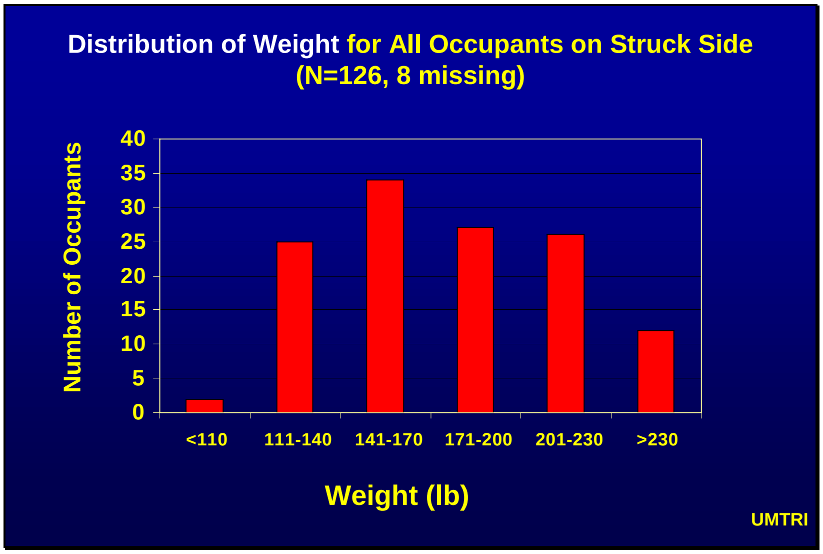

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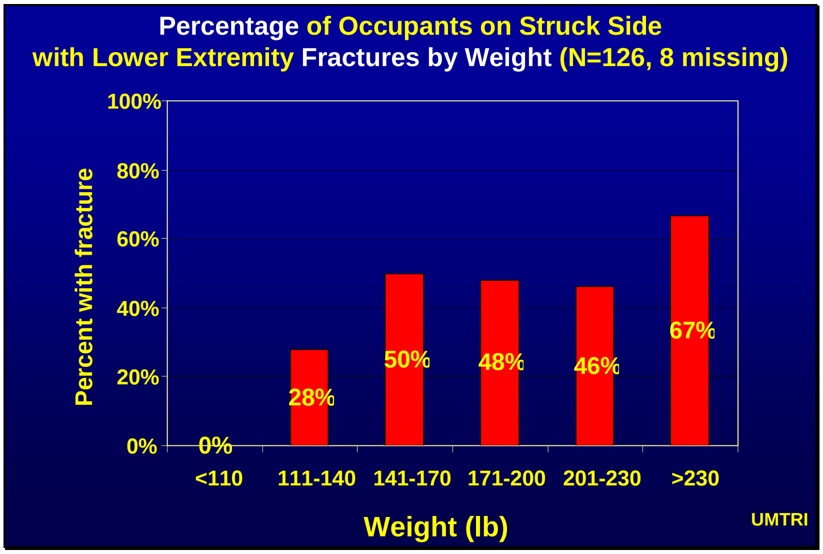
Percentage of Occupants on Struck Side
with Lower Extremity Fractures by Weight (N=126, 8 missing)
100%
80%
60%
40%
20%
0%
Percent with fracture
0%
28%
50%
48%
46%
67%
<110
111-140
141-170
171-200
201-230
>230
Weight (lb)
UMTRI

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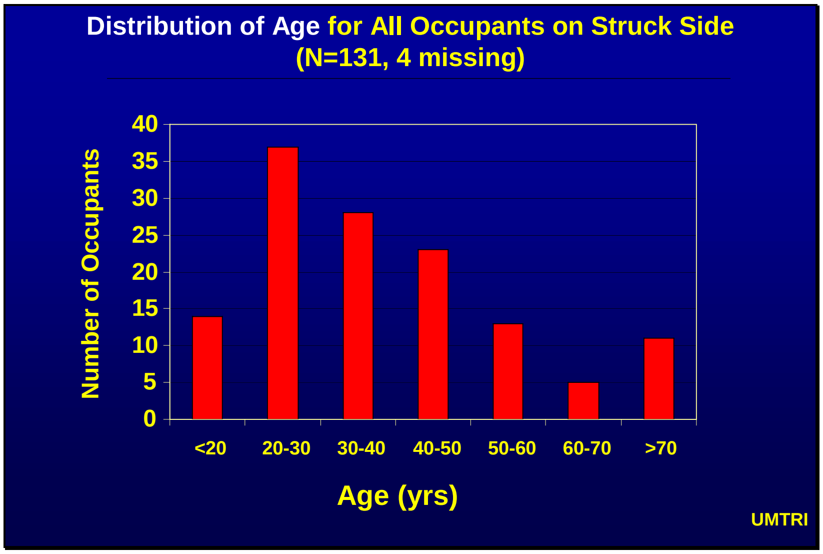

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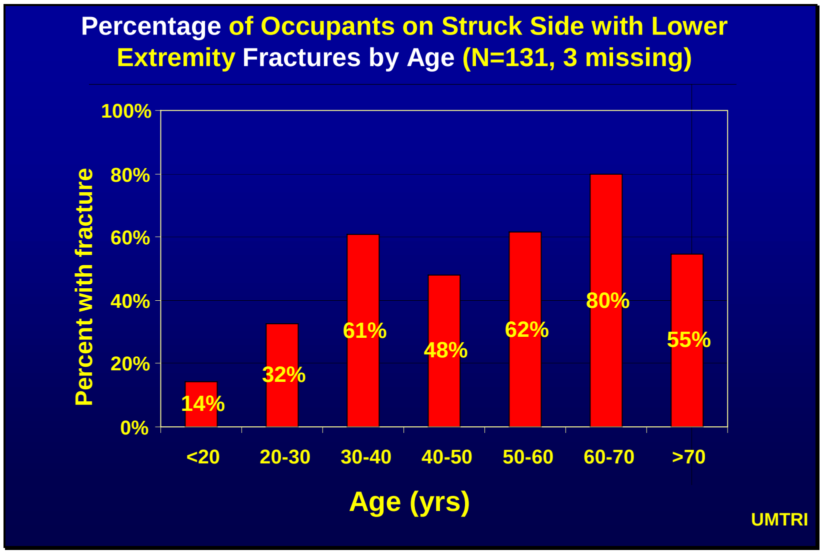
Percentage of Occupants on Struck Side with Lower Extremity Fractures by Age (N=131, 3 missing)
100%
80%
60%
40%
20%
0%
Percent with fracture
14%
32%
61%
48%
62%
80%
55%
<20
20-30
30-40
40-50
50-60
60-70
>70
Age (yrs)
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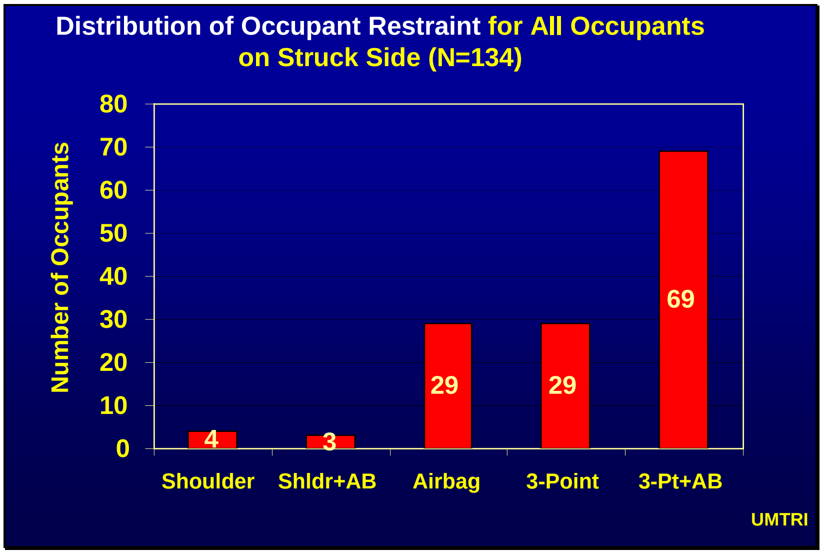

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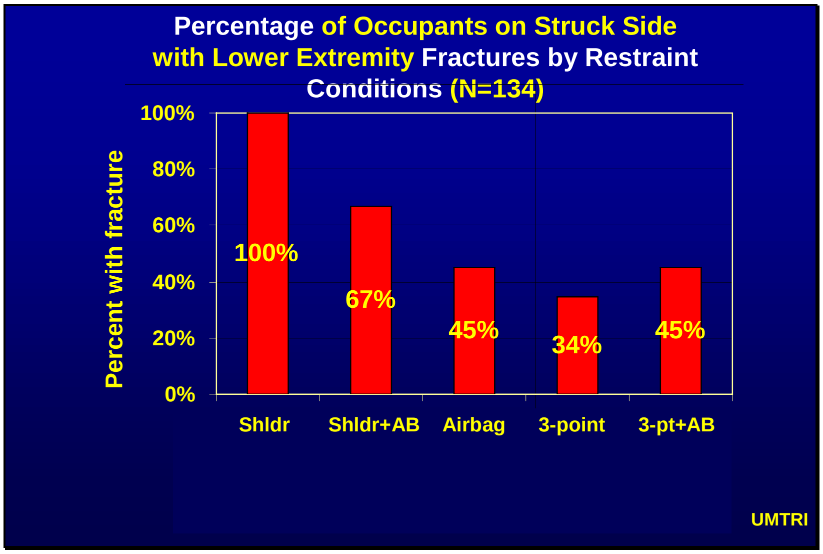
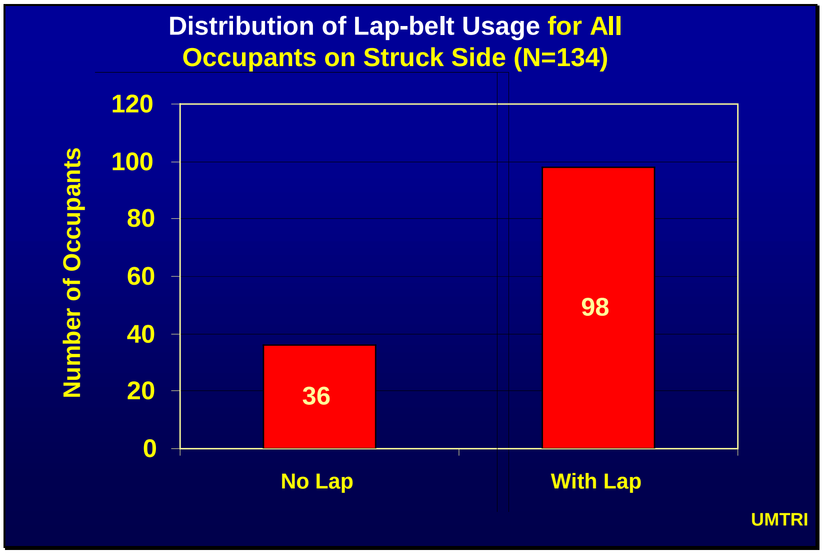
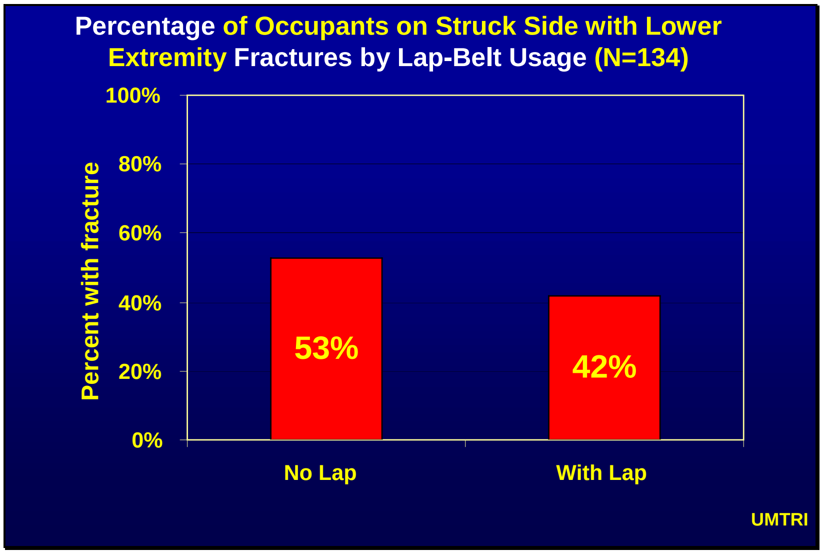



Distribution of Lap-belt Usage for All Occupants on Struck Side (N=134)
Number of Occupants
120
100
80
60
40
20
0
36
98
No Lap
With Lap
UMTRI


Percentage of Occupants on Struck Side with Lower Extremity Fractures by Lap-Belt Usage (N=134)
Percent with fracture
100%
80%
60%
40%
20%
0%
53%
42%
No Lap
With Lap
UMTRI

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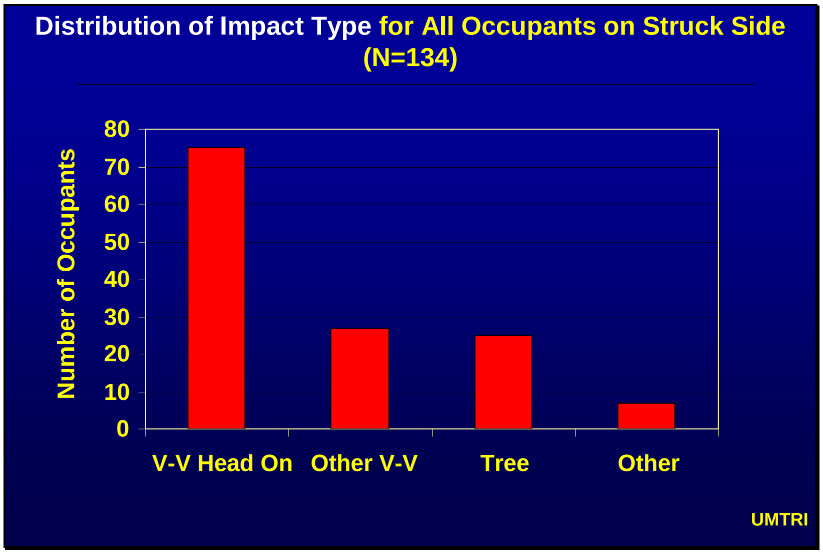

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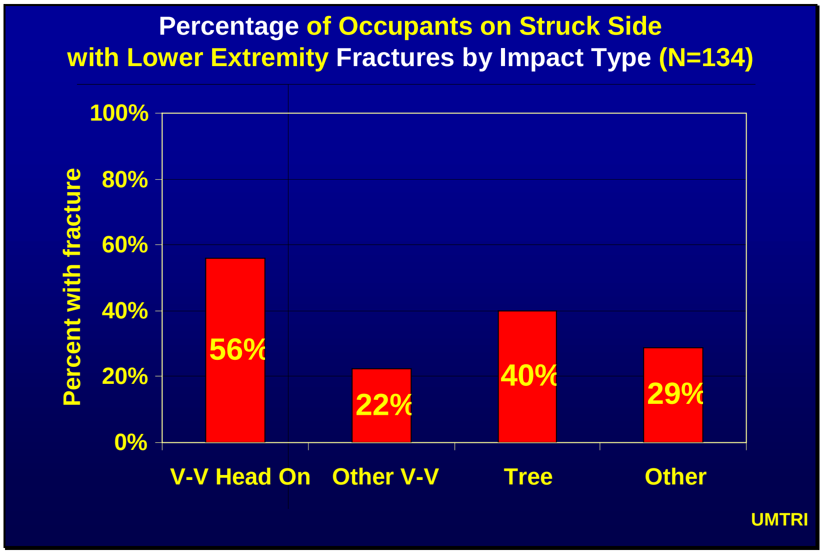
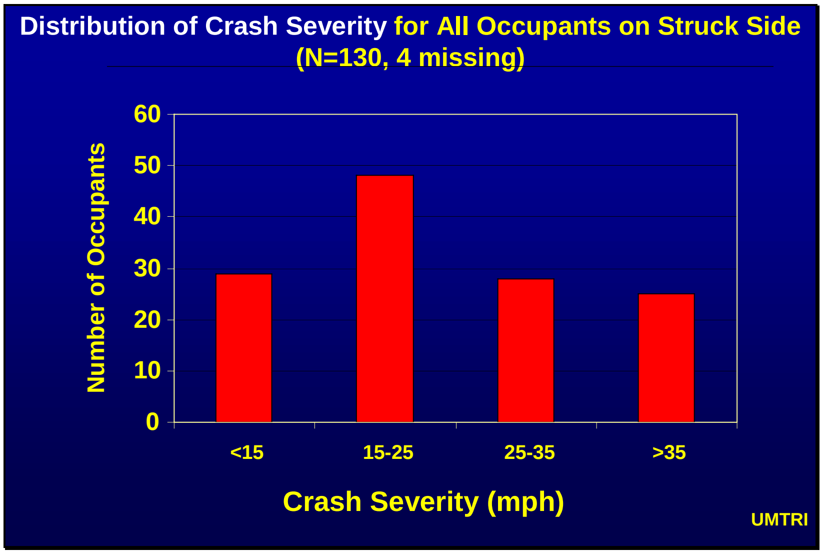
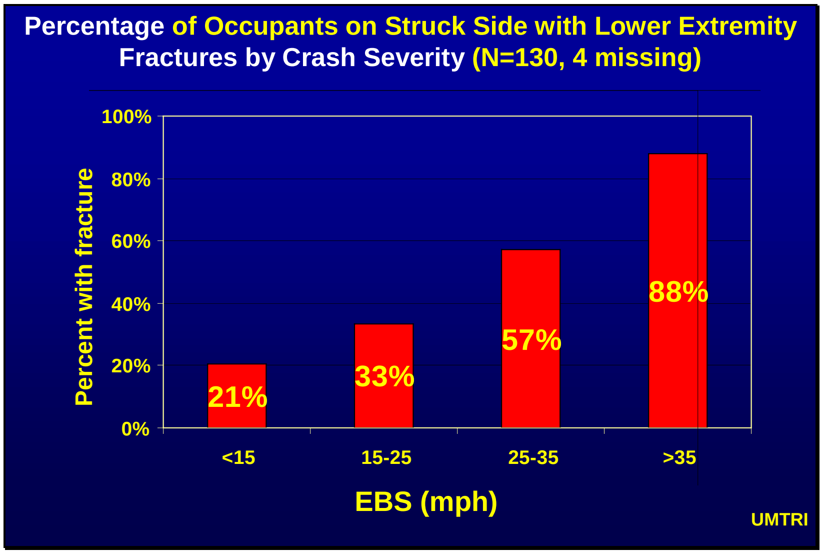



Distribution of Crash Severity for All Occupants on Struck Side
(N=130, 4 missing)
Number of Occupants
60
50
40
30
20
10
0
<15
15-25
25-35
>35
Crash Severity (mph)
UMTRI


Percentage of Occupants on Struck Side with Lower Extremity Fractures by Crash Severity (N=130, 4 missing)
100%
80%
60%
40%
20%
0%
Percent with fracture
21%
33%
57%
88%
<15
15-25
25-35
>35
EBS (mph)
UMTRI

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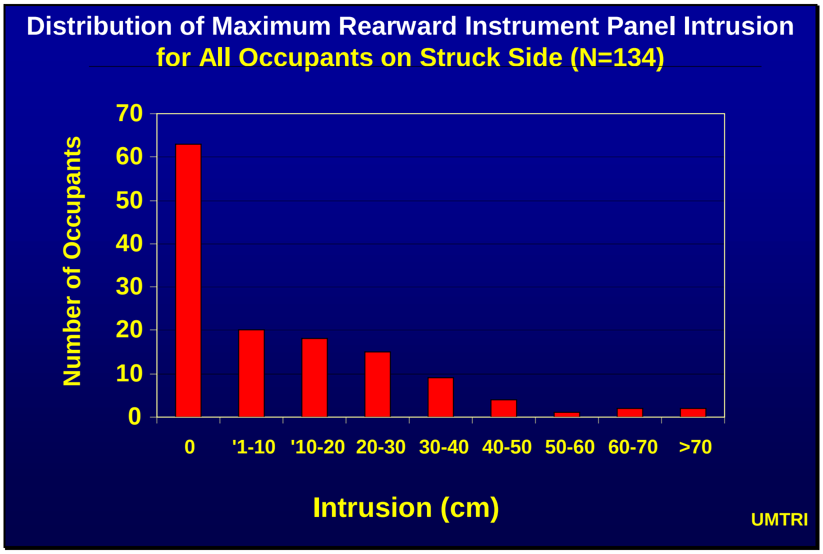
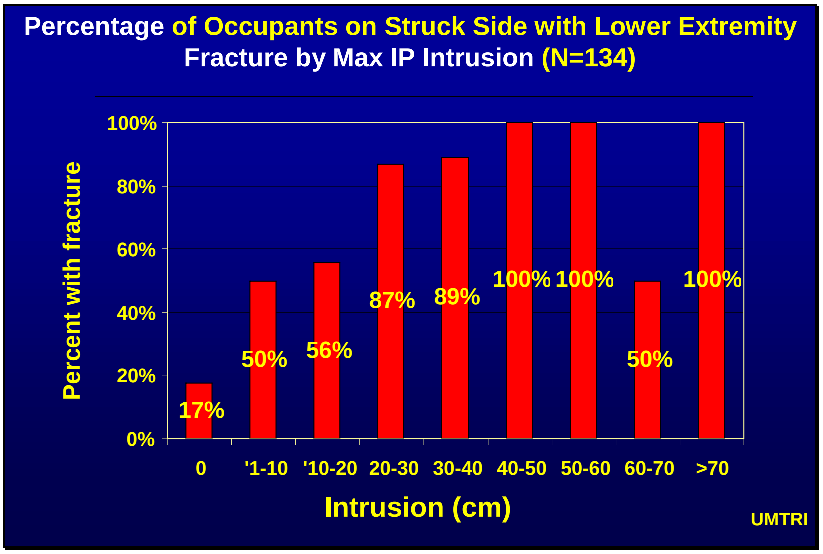
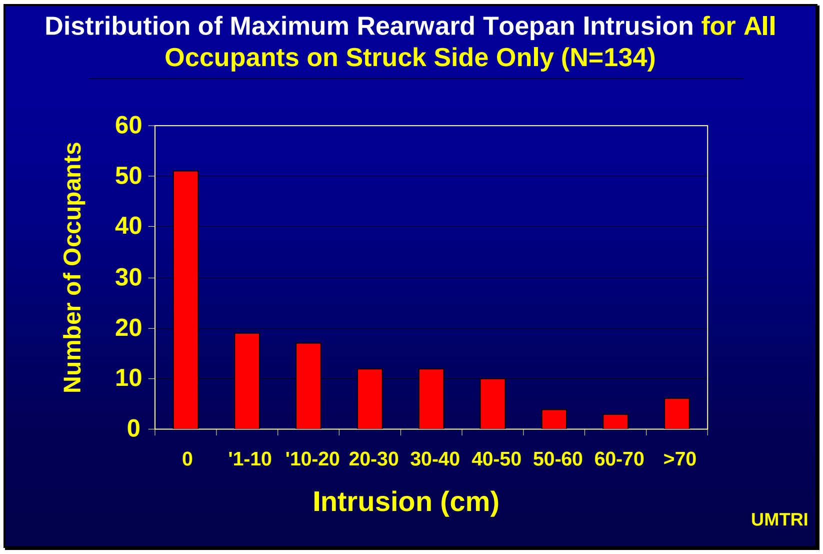



Percentage of Occupants on Struck Side with Lower Extremity Fracture by Max IP Intrusion (N=134)
Percent with fracture
100%
80%
60%
40%
20%
0%
17%
50%
56%
87%
89%
100%
100%
50%
100%
0
'1-10
'10-20
20-30
30-40
40-50
50-60
60-70
>70
Intrusion (cm)
UMTRI


Distribution of Maximum Rearward Toepan Intrusion for All Occupants on Struck Side Only (N=134)
Number of Occupants
60
50
40
30
20
10
0
0
'1-10
'10-20
20-30
30-40
40-50
50-60
60-70
>70
Intrusion (cm)
UMTRI

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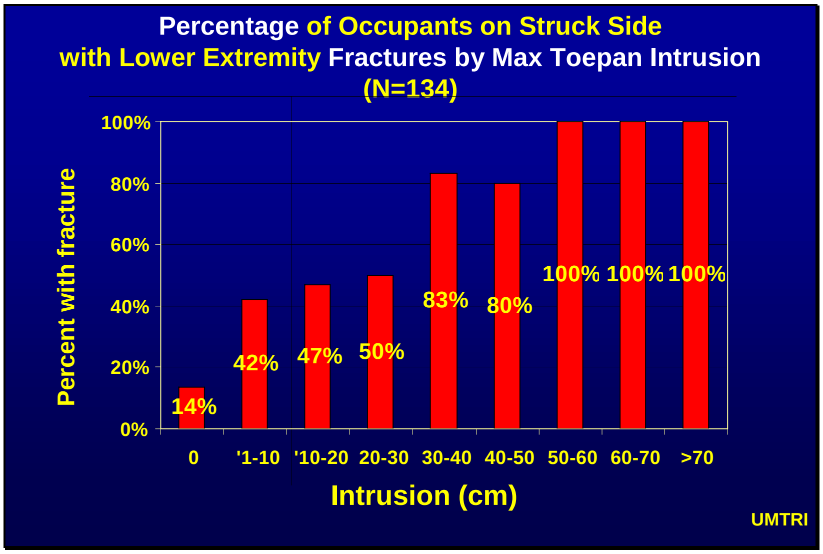

# Determining % Overlap

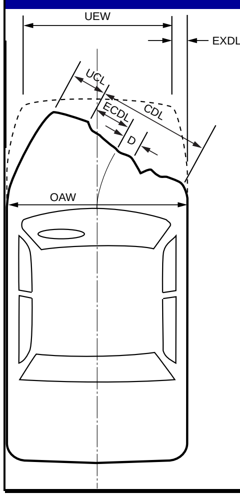


Table 1
Summary of Different methods for Determining FOL and VOL

| Front-End Overlap = FOL | Vehicle Overlap = VOL |
|---|---|
| FOL = [1/2(UEW) ± ECDL]/UEW | VOL = [1/2(OAW) ± ECDL]/OAW |
| FOL = (UEW-UCL)/UEW | VOL = [OAW-(UCL+EXDL)]/OAW |
| FOL = CDL/UEW | VOL = (CDL+EXDL)/OAW |
| FOL = 1 - 2D/UEW | |

UEW = undeformed end width
OAW = overall vehicle width = W103
CDL = Contact Damage Length = length of damage judged to be due to direct loading by the other vehicle or object
ECDL = distance from deflected vehicle centerline to the end of the Contact Damage Length
D = distance from deflected vehicle C/L to center of Contact Damage Length
UCL = uncontacted length
EXDL = extended damage length = 1/2(OAW-UEW)

Notes: CDL , UCL, ECDL, and D are measured along the damaged front plane
FOL and VOL are expressed as percents

UMTRI

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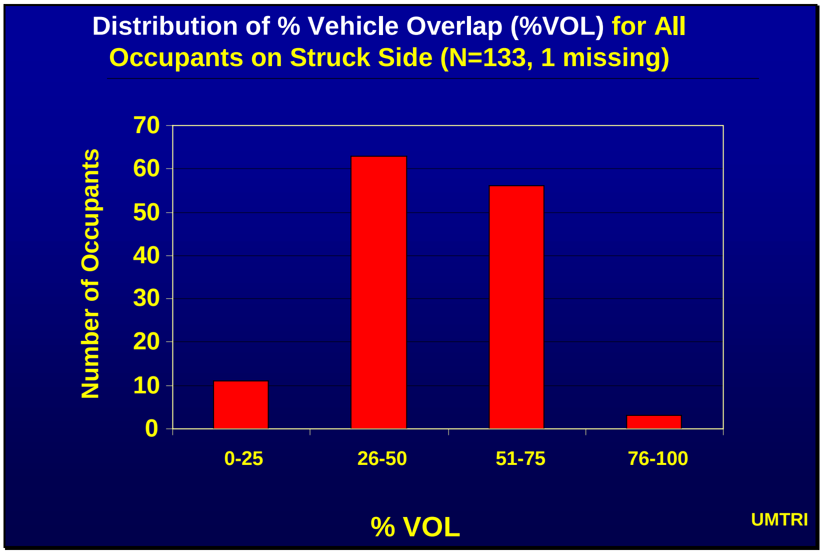
Distribution of % Vehicle Overlap (%VOL) for All Occupants on Struck Side (N=133, 1 missing)
Number of Occupants
70
60
50
40
30
20
10
0
0-25
26-50
51-75
76-100
% VOL
UMTRI

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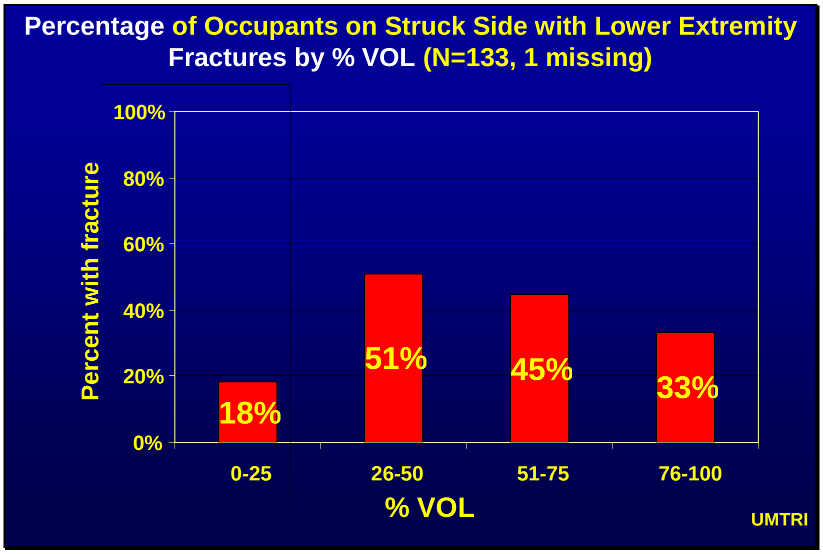
Percentage of Occupants on Struck Side with Lower Extremity Fractures by % VOL (N=133, 1 missing)
Percent with fracture
100%
80%
60%
40%
20%
0%
18%
51%
45%
33%
0-25
26-50
51-75
76-100
% VOL
UMTRI

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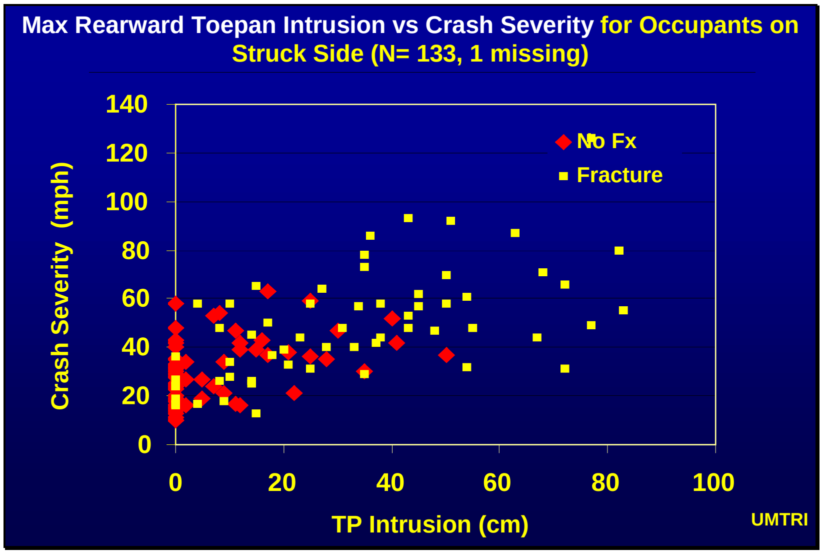
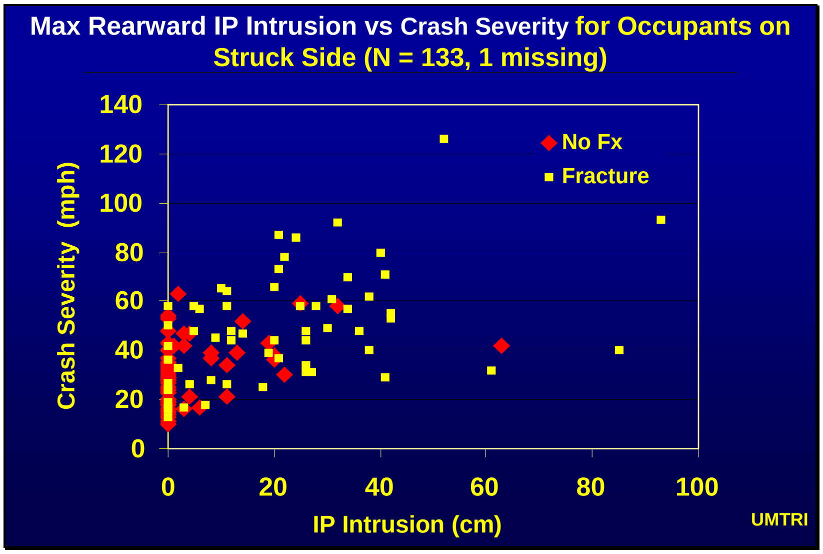
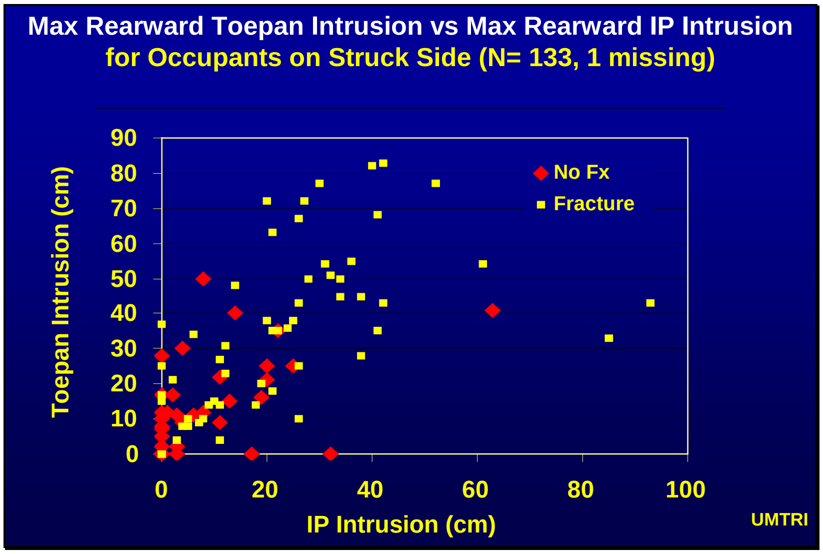
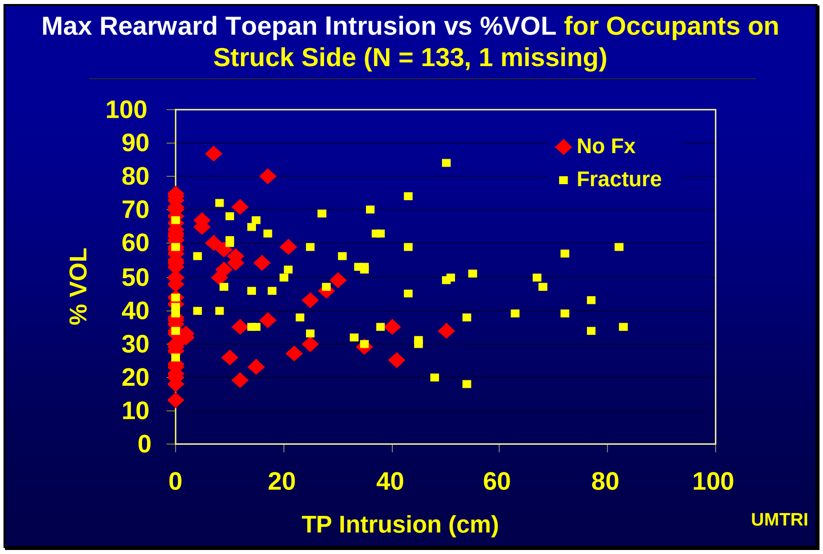

Max Rearward Toepan Intrusion vs Crash Severity for Occupants on Struck Side (N= 133, 1 missing)
Crash Severity (mph)
140
120
100
80
60
40
20
0
0
20
40
60
80
100
TP Intrusion (cm)
No Fx
Fracture
UMTRI


Max Rearward IP Intrusion vs Crash Severity for Occupants on Struck Side (N = 133, 1 missing)
Crash Severity (mph)
140
120
100
80
60
40
20
0
0
20
40
60
80
100
IP Intrusion (cm)
No Fx
Fracture
UMTRI


Max Rearward Toepan Intrusion vs Max Rearward IP Intrusion
for Occupants on Struck Side (N= 133, 1 missing)
Toepan Intrusion (cm)
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
IP Intrusion (cm)
No Fx
Fracture
UMTRI


Max Rearward Toepan Intrusion vs %VOL for Occupants on Struck Side (N = 133, 1 missing)
% VOL
TP Intrusion (cm)
No Fx
Fracture
0
10
20
30
40
50
60
70
80
90
100
UMTRI

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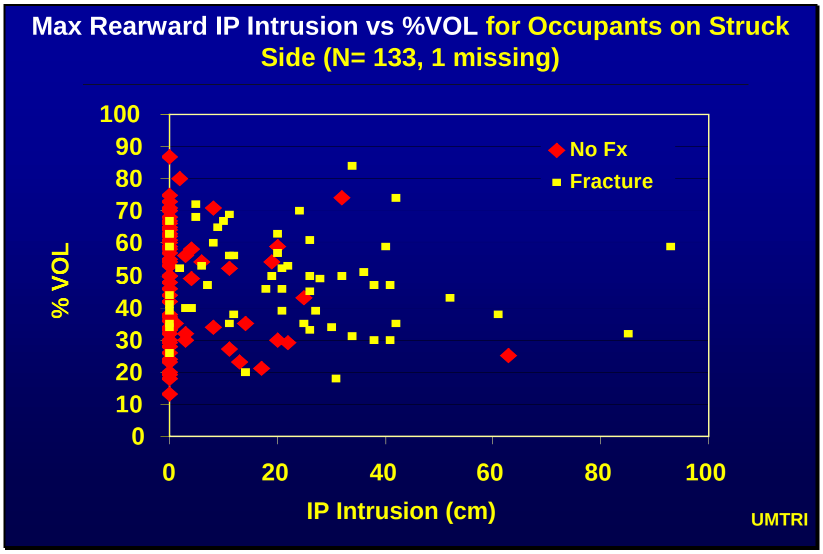

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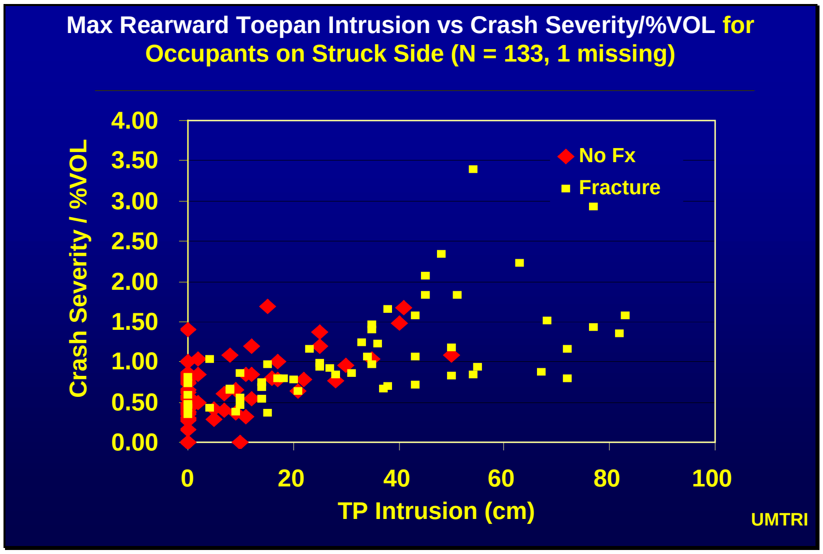

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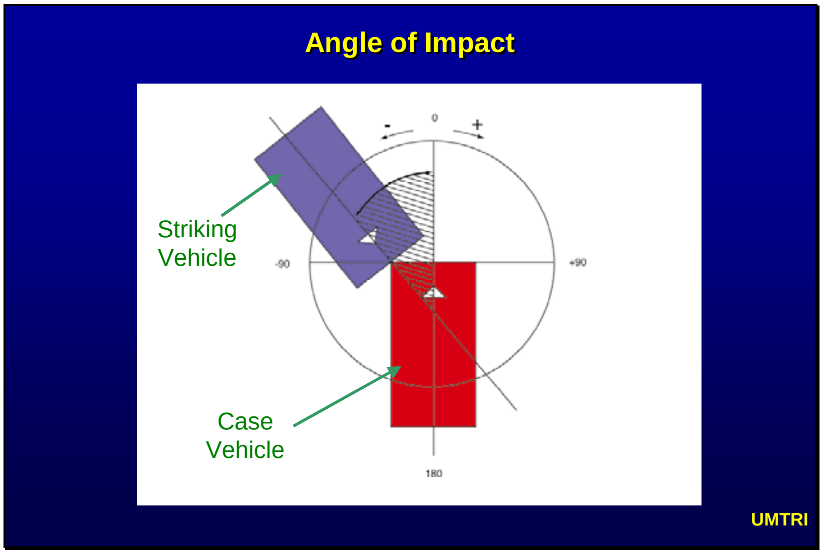

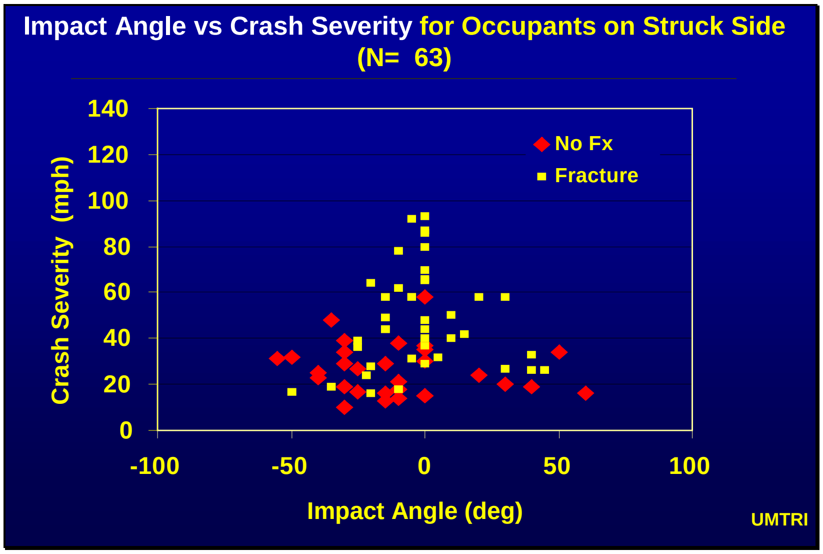
Impact Angle vs Crash Severity for Occupants on Struck Side
(N= 63)
Crash Severity (mph)
140
120
100
80
60
40
20
0
-100
-50
0
50
100
Impact Angle (deg)
No Fx
Fracture
UMTRI

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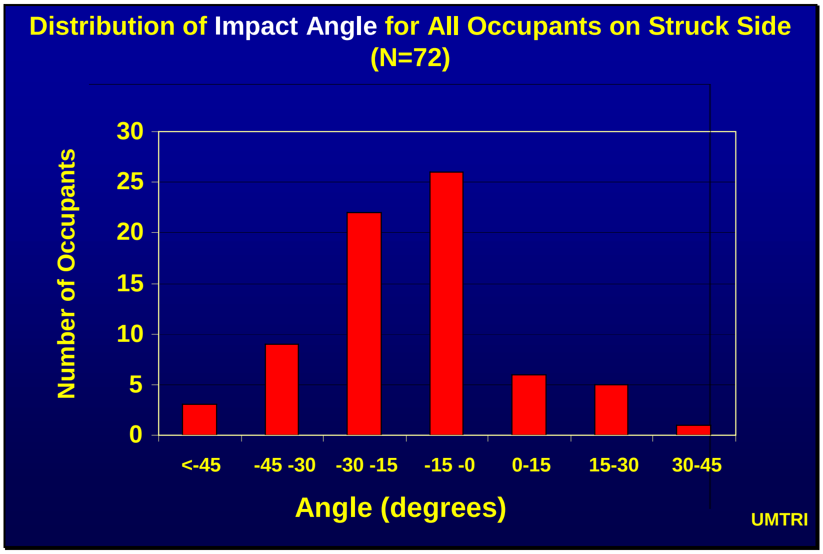
Distribution of Impact Angle for All Occupants on Struck Side
(N=72)
Number of Occupants
0
5
10
15
20
25
30
<-45
-45 -30
-30 -15
-15 -0
0-15
15-30
30-45
Angle (degrees)
UMTRI

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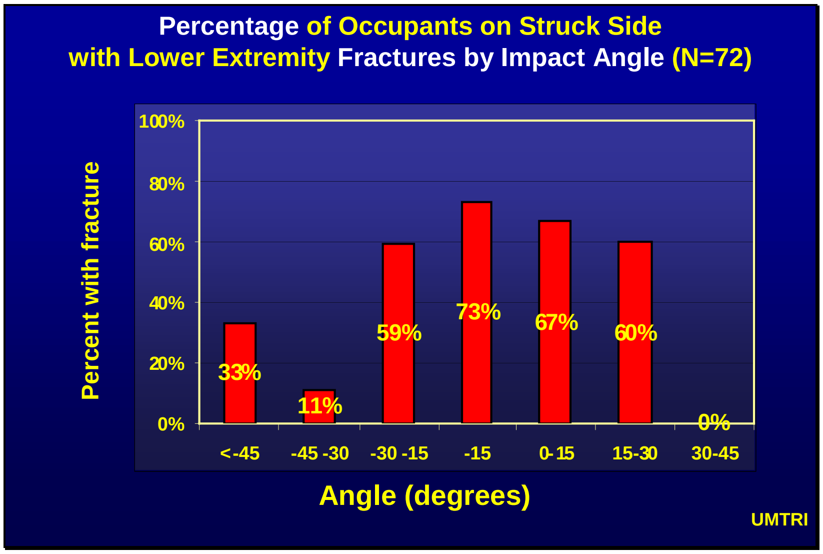

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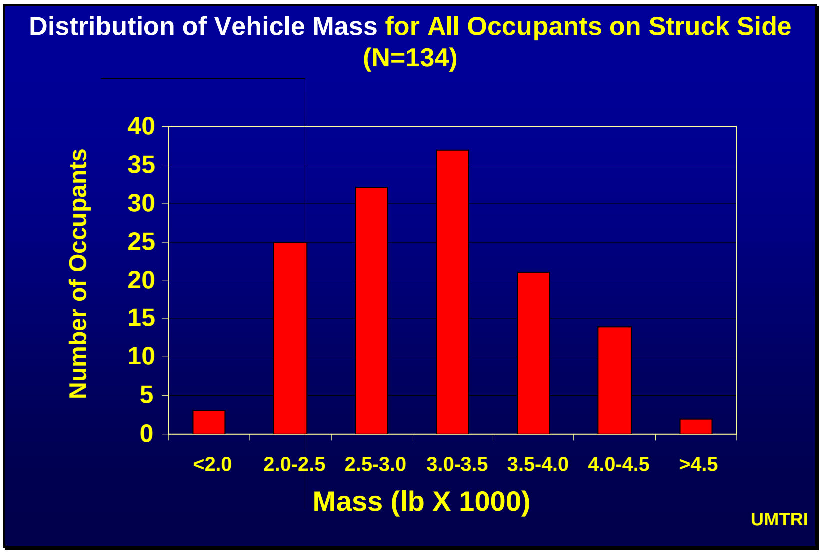
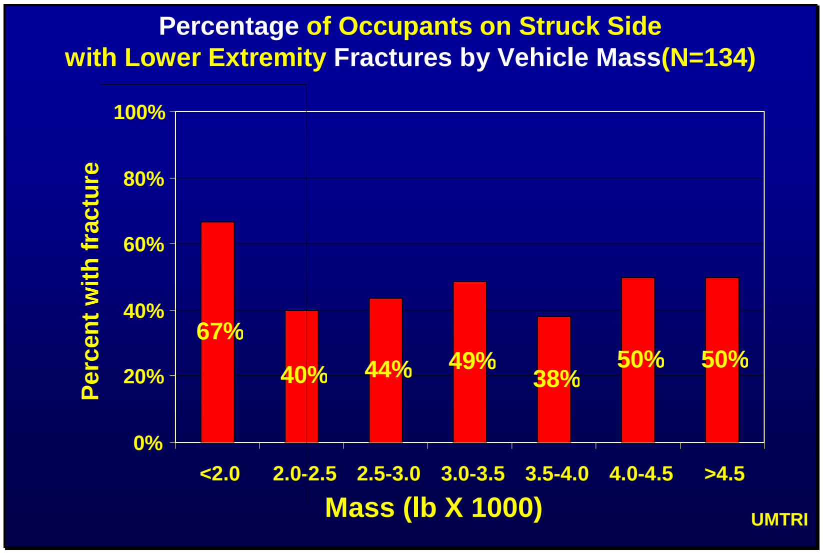
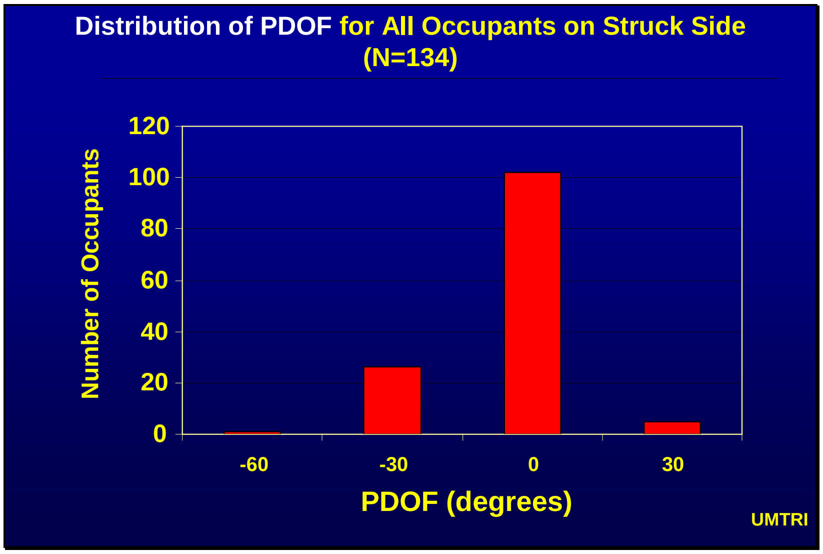



Percentage of Occupants on Struck Side
with Lower Extremity Fractures by Vehicle Mass(N=134)
100%
80%
60%
40%
20%
0%
Percent with fracture
67%
40%
44%
49%
38%
50%
50%
<2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
>4.5
Mass (lb X 1000)
UMTRI


Distribution of PDOF for All Occupants on Struck Side
(N=134)
Number of Occupants
0
20
40
60
80
100
120
-60
-30
0
30
PDOF (degrees)
UMTRI

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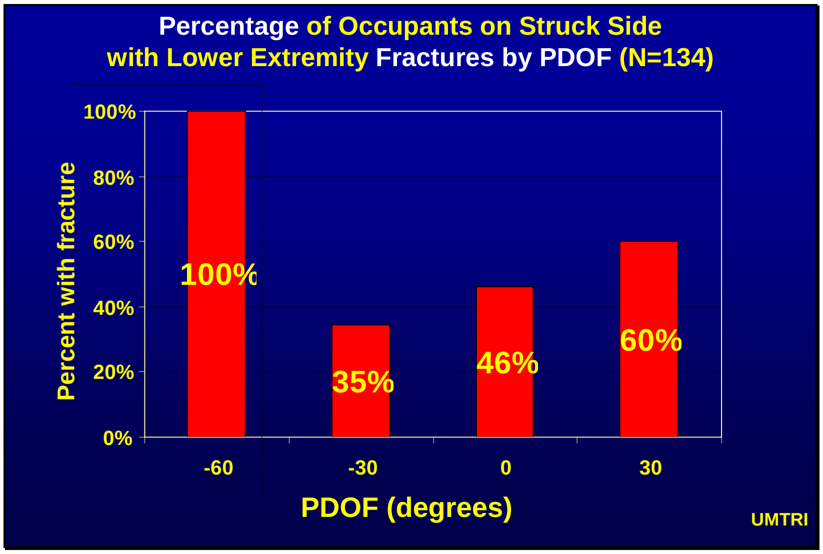

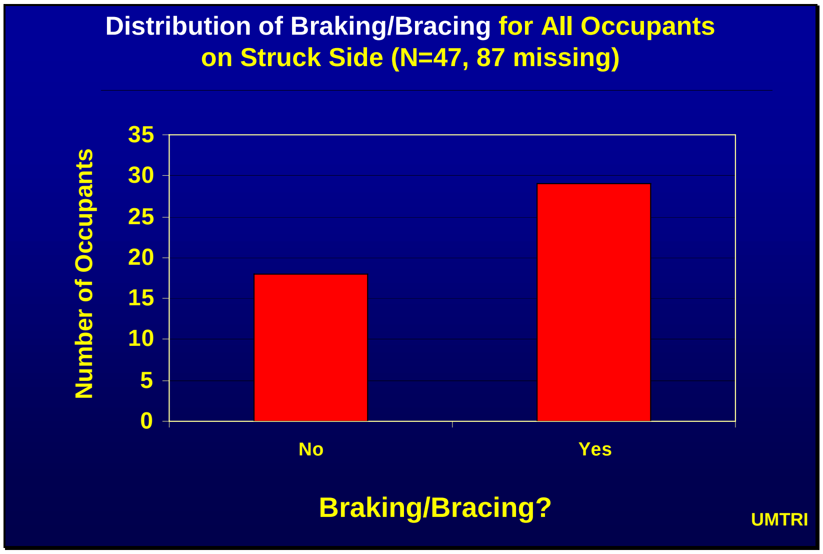
Distribution of Braking/Bracing for All Occupants
on Struck Side (N=47, 87 missing)
Number of Occupants
35
30
25
20
15
10
5
0
No
Yes
Braking/Bracing?
UMTRI

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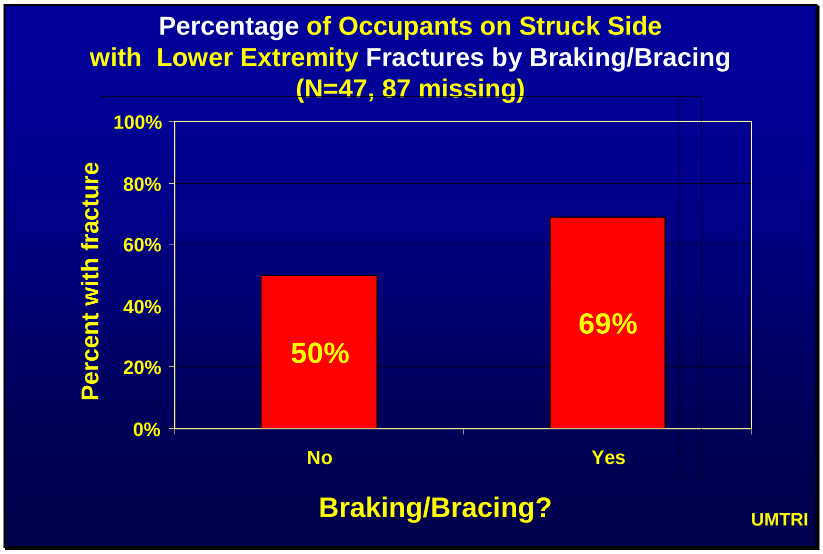

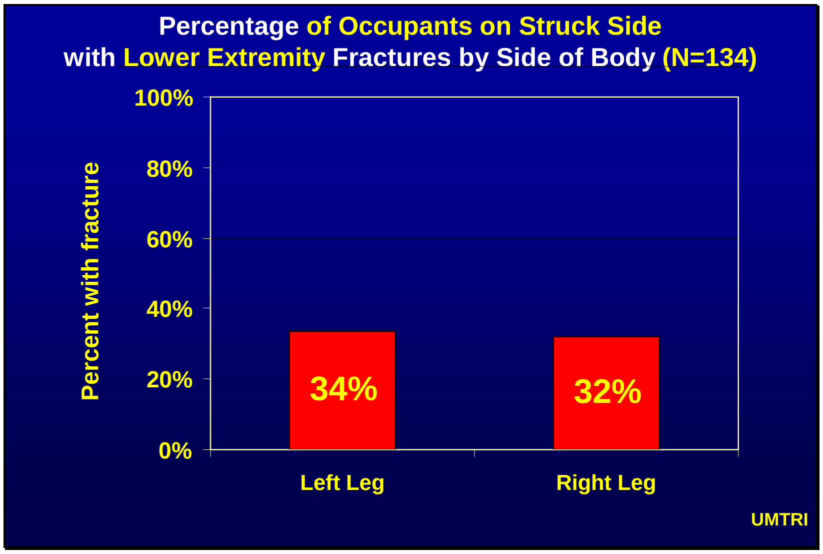
Percentage of Occupants on Struck Side
with Lower Extremity Fractures by Side of Body (N=134)
Percent with fracture
100%
80%
60%
40%
20%
0%
34%
32%
Left Leg
Right Leg
UMTRI

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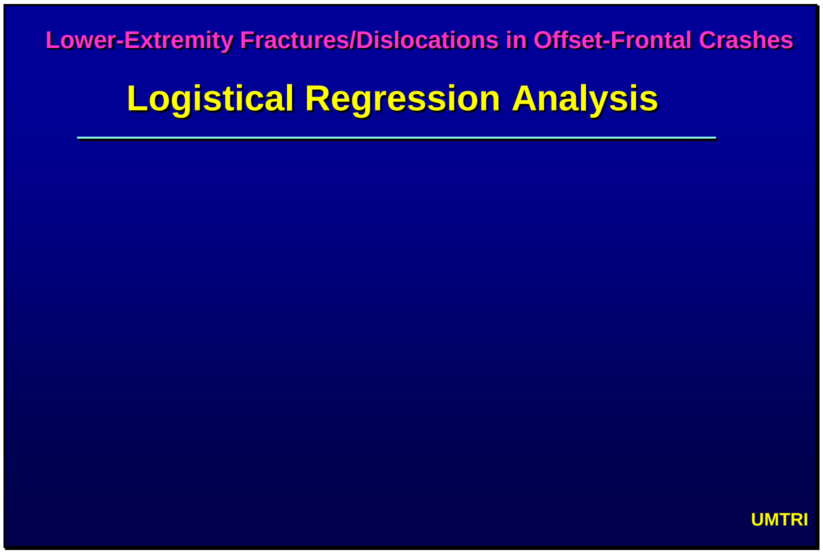

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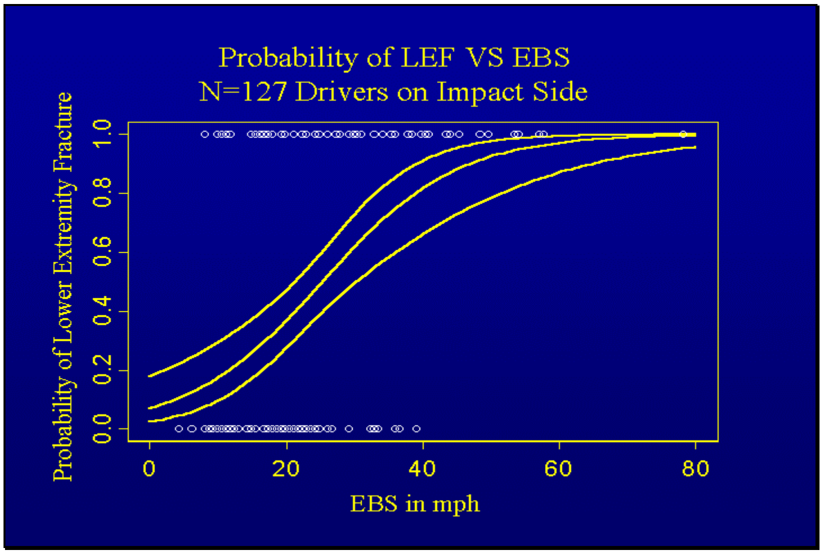
Probability of LEF VS EBS
N=127 Drivers on Impact Side
Probability of Lower Extremity Fracture
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
EBS in mph

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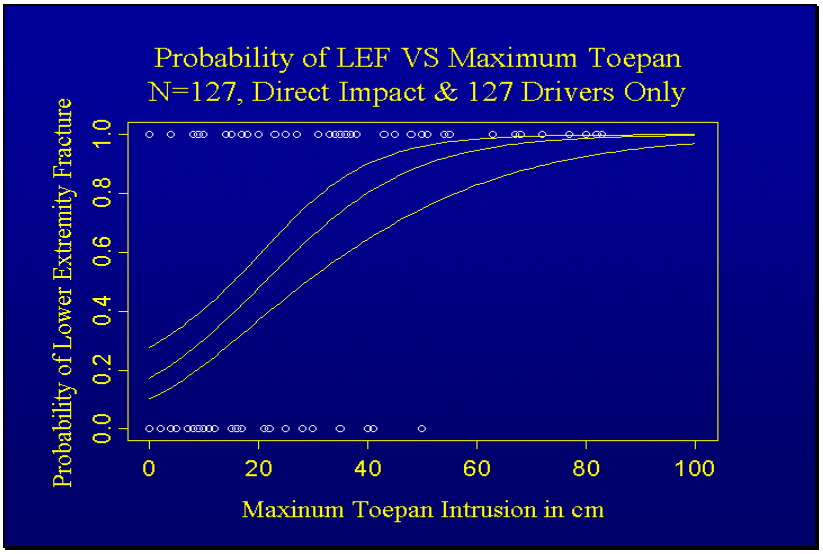
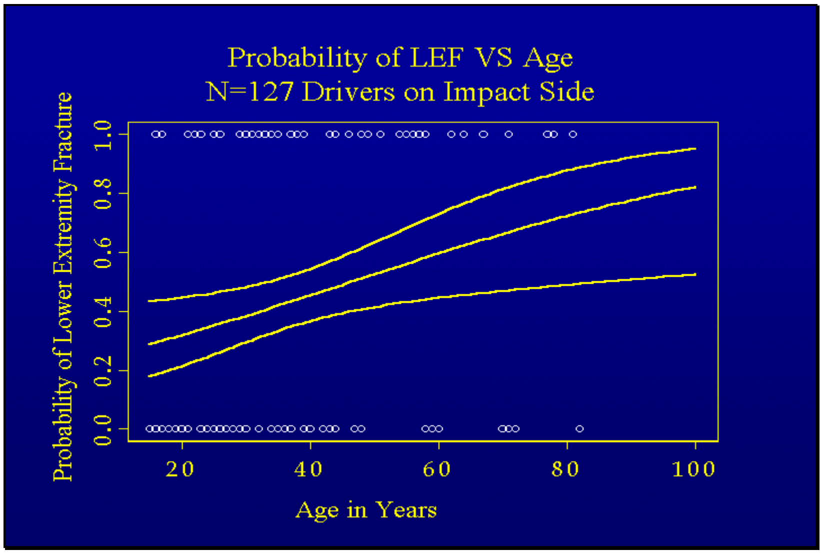
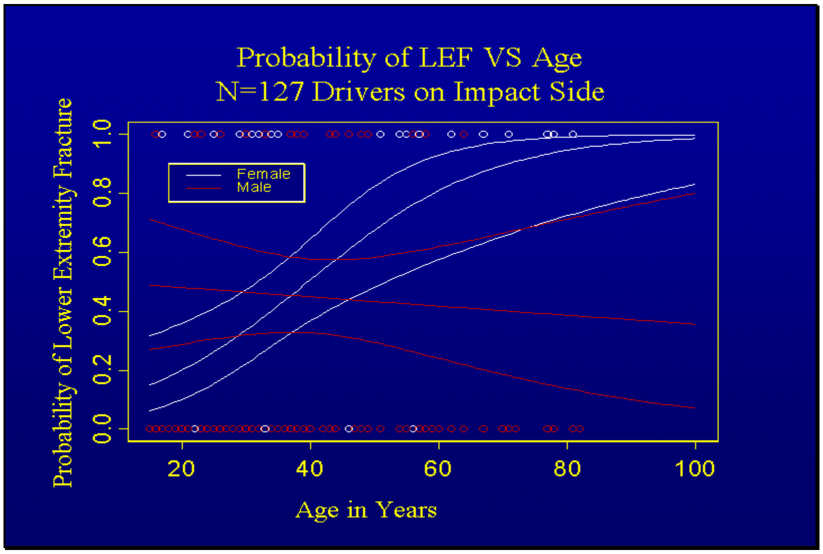



Probability of LEF VS Age
N=127 Drivers on Impact Side
Probability of Lower Extremity Fracture
0.0
0.2
0.4
0.6
0.8
1.0
20
40
60
80
100
Age in Years


Probability of LEF VS Age
N=127 Drivers on Impact Side
Probability of Lower Extremity Fracture
0.0
0.2
0.4
0.6
0.8
1.0
Female
Male
20
40
60
80
100
Age in Years

**Use of Crash/Injury Databases for Developing Conditions of Staged Frontal Crash Tests Relative to Assessment of Injury to the Lower Extremities**

**University of Michigan Transportation Research Institute**

June 25, 2004

## Introduction

In developing staged crash tests for assessing the effectiveness of vehicle and restraint countermeasures relative to reducing the incidence of particular types of injuries, analysis of in-depth crash/injury databases can provide valuable guidance to establishing the most appropriate and useful test conditions and parameter values. With regard to determining the need for, and conditions of, a new frontal crash test for assessing the likelihood of disabling lower-extremity injuries, three databases are available for analysis. These include, the National Automotive Sampling System (NASS) database, the UMTRI database, and the CIREN database.

In using any of these databases, only frontal crashes of late-model airbag equipped vehicles should be used, since restraint performance and occupant kinematics in earlier model vehicles may not be relevant to future vehicles for which the tests will be used. In addition, the analyses should be restricted to cases in which there were no other impact or rollover events (other than the frontal crash) that are likely to have resulted in AIS 2+ occupant injuries to the lower extremities, so that those injuries included in the analysis are known to be due to the frontal crash. Finally, the cases that will be of greatest value in the analyses are those for which the crash severity of the frontal crash has a reasonable probability of resulting in an AIS 2+ lower-extremity injury to adult front-seat occupants. That is, cases in which the frontal crash is of a relatively low severity are unlikely to result in AIS 2+ lower-extremity injuries and are of little value to analyses that seek to determine the important crash conditions for assessing the effectiveness of vehicle crashworthiness and restraint-system designs in reducing the likelihood of lower-extremity injuries.

## Data Analyses

Analyses of these databases will attempt to find statistically significant relationships (i.e., correlations) between a wide range of crash, vehicle, restraint, and occupant variables to lower-extremity injury outcomes. A list of potential independent variables is listed in Table 1. Relative to determining the important conditions and levels of conditions for a new frontal crash test, the most important independent variables are those related directly to the crash event, including the crash severity (delta V or EBS), the angle of impact and/or principle direction of force (PDOF), the extent of vehicle overlap (%VOL), and the location of impact (i.e., which portion of the front end was directly loaded). In addition, a key issue that the analyses should try to address is the role of rearward intrusion of vehicle components, such as the toepan and the knee bolster, in causing disabling lower-extremity injuries, independent of the role of crash severity. Thus, the analysis should attempt to distinguish the relative roles of these two factors, which are typically highly correlated, with regard to the likelihood of lower-extremity injuries, perhaps by comparing injury outcomes to occupants on the struck and the un-struck side for frontal crashes with percent overlaps between 25 and 60 %VOL.

Other independent variables that should be included in the analyses are the occupant factors of age, gender, stature, and weight, occupant position within the vehicle (i.e., driver versus passenger), restraint usage (particularly the use or nonuse of a lap belt), and, when known, the presence or absence of occupant bracing or braking. The latter variable is often not known for many case occupants and is not typically coded in the database. However, in many cases, there is clear evidence of occupant braking and/or bracing, or clear evidence that the occupant was unconsciousness because of a medical condition, falling asleep, or intoxication, especially for drivers. In these instances, a variable can be added to the database to include this factor in a subset of the cases.

Table 1
Crash, Vehicle, Occupant, and Restraint Variables

| | |
|---|---|
| Vehicle Variables | |
| | Model year |
| | Vehicle Weight |
| | Vehicle Type Type |
| | Maximum rearward toepan intrusion |
| | Maximum rearward knee-bolster intrusion |
| Crash Variables | |
| | Crash Severity |
| | % Overlap |
| | PDOF |
| | Angle of Impact to vehicle centerline |
| | Location of impact along front end |
| | Type of vehicle or object struck |
| Occupant Variables | |
| | Location (driver, right-front passenger) |
| | Location relative to damage location |
| | Gender |
| | Age |
| | Stature |
| | Weight |
| | Braking/bracing versus relaxed/unconscious |
| Restraint Variables | |
| | Belt restraint |
| | Airbag |

The dependent or injury variables should be included in the analysis using the maximum injury severity, or MAIS, for the complete lower extremities (i.e., from the pelvis to the foot), as well as for different groupings of lower-extremity body regions, since the causes or mechanisms of injury can vary significantly. For example, the analyses should be performed for injuries to the combination of knee, thigh, and hip separate from the combination of the leg, ankle, and foot, and perhaps for the foot/ankle separate from the leg, and for the knee and hip separate from the thigh. In addition, the analyses should be performed to examine the relationship between the side of the body (i.e., right or left, or both) to which the lower-extremity injury occurred in relation to the independent crash factors, as this can provide additional insight into the causes of injury that are important to represent in the crash test.

The analyses performed for these independent and dependent variables will include multivariate and multivariate logistic regression analysis, as well as univariate analysis in which the frequency of injury outcomes are examined for different levels of each independent variable. With regard to the logistic regression analysis, the injury outcome data for the different groupings of lower-extremity body regions is converted to bivariate injury and no-injury outcomes, where injury is defined as AIS 2 or greater, and possibly as AIS 3 or greater.

## *Advantages and Disadvantages of the Different Databases*

### **NASS Database**

Of the three databases noted above, the NASS database potentially provides the largest number of frontal crashes on which the analyses of interest might be performed. However, a large percentage of the cases in the NASS database are not particularly useful with regard to the objectives and analyses described above, so it should not be assumed that the NASS database is the first choice to achieve the stated goals.

Because crashes in the NASS database constitute a weighted sample of real-world crashes that has been designed to allow estimation of the national per-annual magnitude of a particular crash/injury problem (e.g., how many hip fractures occur in frontal crashes in the U.S. each year), the crash variables of interest in a large percentage of NASS-investigated frontal crashes are well below the levels at which disabling lower-extremity injuries typically occur. For example, most lower-extremity injuries of interest probably occur in moderate to high severity crashes with delta Vs greater than 15 mph. Yet, even though NASS sampling is weighted toward selection of a disproportionate number of more severe crashes, in more than three-fourths of the frontal crashes in the NASS database, the crash severity for the case vehicle was less than 15 mph delta V.

In addition, crashes are selected for investigation in the NASS based on statistical sampling requirements, regardless of whether a full vehicle inspection can be completed, a full interview with the case occupant or occupants is conducted, or injury data from a medical facility can be obtained. Because of this approach, a relatively large percentage of NASS cases (perhaps as much as 50% of frontal crashes) are lacking in quantitative data on crash and vehicle factors and/or measurements from complete vehicle inspection, and/or are lacking in lower-extremity injury data, that are needed to perform the analyses described above.

Finally, while it is possible to select NASS cases where the frontal crash has been designated as the primary injury-producing event, these cases often involve other crash and rollover events for which the severity is unknown. This leads to uncertainty as to whether the injury outcomes are due to the frontal crash conditions documented in the case that would be used in the analyses described above.

**UMTRI and CIREN Databases**

Unlike NASS, UMTRI and CIREN databases are comprised of cases that were not sampled in a manner that allows for extrapolation of the data to estimate the national magnitude of a particular injury problem in a particular type of crash event. Rather, these databases are biased toward more severe crashes and injury outcomes. This means that a greater percentage of the crashes in these databases are useful in terms of analyzing the relationships between crash factors and injury outcomes. For example, in a recent analysis of NASS frontal crashes relative to airbag effectiveness, it was found that only about 25% of NASS frontal crashes are greater than 15-mph delta V. In contrast, about 75% of UMTRI frontal crashes are 15-mph delta V or greater.

In addition, all crashes in the UMTRI and CIREN databases involve a full vehicle inspection, such that, whenever the nature of the crash allows it (e.g., not too narrow of an impact or too much underride or override), a quantitative reconstruction of the crash severity is performed and included in the case record using the latest crash-reconstruction programs. Whenever possible and appropriate, this reconstruction includes inspection and measurement of a crush profile on the other involved vehicle, which further enhances the accuracy of the reconstruction.

All UMTRI and CIREN non-fatal crashes also include occupant interview and/or injury data. In both programs, a high percentage of the cases include injury data obtained from the treating medical facility. Since CIREN cases are based on patients admitted to a level-1 trauma center, every case involves injury data from the treating facility and these injury data are available in great detail, although the coding of the data in the CIREN Oracle database is done at the same level as in NASS and UMTRI data using AIS injury coding. Thus, for data analysis purposes, the CIREN cases do not offer any additional injury detail than cases in NASS and the UMTRI database for which injury data from the treating medical facility have been obtained. The potential to perform analyses using more detailed injury data therefore exists with the CIREN cases, but requires a very significant effort to extract the higher level of injury data from the case file and code it into a database for analysis.

While both the UMTRI and CIREN databases are biased toward more significant crash events and injury outcomes, there are some important differences in the distributions of cases in the two databases. One difference is that CIREN cases are occupant-based, rather than crash based, such that each case is identified and selected from the population of trauma patients admitted to specific level-1 trauma centers. These cases are therefore primarily biased toward occupants who have sustained significant injuries. While CIREN selection criteria place some limitations on the types of crashes that are investigated, these are generally secondary considerations and there is relatively little control on the type of crash or the number of crashes in which the case occupant’s vehicle was involved. Thus, for an analysis with regard to the relationship between frontal crash factors and lower-extremity injuries, many frontal crashes in the CIREN database also involve injuries that have been caused by events other than the frontal crash of interest.

In contrast, cases in the UMTRI database are identified and selected from vehicle damage information on police accident reports and are thus biased toward more significant crash events, regardless of the injury outcome. Moreover, since one of the primary objectives of the UMTRI crash-investigation program is to study the relationships of crash and restraint factors to injury, UMTRI investigations are generally not completed and included in the database when it is learned during a preliminary investigation that the case vehicle was involved in more than one injury-producing event.

## *Summary*

While NASS, CIREN, and UMTRI databases can all be used to perform crash/injury analyses relative to establishing the need for, and conditions of, a new staged frontal crash test for improved assessment of lower-extremity injuries, the UMTRI database is considered to provide the most suitable and reliable data for this purpose and will therefore be used to perform the initial analyses. Because a significant focus of industry-and-Alliance-sponsored UMTRI investigations since the early1990s has been on frontal crashes, primarily to investigate airbag performance but also to investigate lower-extremity injuries in offset-frontal crashes, a large percentage of the UMTRI crashes investigated in the past ten to fifteen years have been single-event frontal crashes. As a result, the UMTRI database contains approximately 610 frontal crashes of airbag-equipped vehicles, all of which include reconstruction of the crash severity based on a full vehicle inspection and measurements of vehicle crush from the case vehicle and, in many cases, from the other involved vehicle. These frontal crashes span a wide range of percent overlap, including crashes will full or nearly full front-end engagement, so that the analyses performed can examine the importance of this variable as well as the role of rearward intrusions in the occurrence of lower-extremity injuries.

These 600+ frontal crashes include injury data on approximately 760 adult or adult-size front-seat occupants, whose gender, stature, and weight are also generally known. All of these cases also include good evidence of occupant belt-restraint usage and airbag deployment based on inspection of the vehicle interior. They also include AIS-coded injury data obtained primarily from the treating medical facility or medical examiner. UMTRI crash/injury data have been collected by a relatively small set of field investigators, each of whom have ten or more years experience performing in-depth crash investigation. The data and reports for each case are carefully reviewed and quality controlled by a multidisciplinary team that includes significant biomechanical expertise.